# 5.0 DOSE MODELING

**PURPOSE OF THIS SECTION**

The purpose of this section is to describe dose modeling performed for Phase 1 of the proposed decommissioning to establish cleanup criteria that would not limit options for Phase 2 of the decommissioning.

**INFORMATION IN THIS SECTION**

This section provides the following information:

- Section 5.1 contains introductory material to place information in the following sections into context.
- Section 5.2 describes the three conceptual models and the mathematical model (RESRAD) used to develop derived concentration guideline levels (DCGLs) for 18 radionuclides of interest in surface soil, subsurface soil, and streambed sediment. It identifies the results in terms of $DCGL_W$ values and $DCGL_{EMC}$ values. It also discusses the results of deterministic sensitivity analyses of model input parameters.
- Section 5.3 discusses considerations related to dose integration and describes analyses performed to ensure that cleanup criteria used in Phase 1 would not limit Phase 2 decommissioning options.
- Section 5.4 provides cleanup goals; describes the process for refining the DCGLs and these cleanup goals; addresses use of a surrogate radionuclide in field measurements; provides a preliminary, order-of-magnitude dose assessment related to remediation of subsurface soil; and provides for a final such dose assessment after completion of the Phase 1 final status surveys.

**RELATIONSHIP TO OTHER PLAN SECTIONS**

To put into perspective the information in this section, one must consider:

- The information in Section 1 on the project background and those facilities and areas within the scope of this plan,
- The facility descriptions in Section 3,
- The information on site radioactivity in Section 4,
- The information in Section 6 on the as low as reasonably achievable (ALARA) analysis,
- The information in Section 9 on characterization surveys and the Phase 1 final status survey,
- The information in Appendix C that supplements the content of this section, and
- The information in Appendix D on engineered barriers and groundwater flow fields.

## 5.1 Introduction

To help place the dose modeling into context, it is useful to consider information about the applicable requirements and guidance, information on the environmental media of interest, and information relevant to consideration of doses from different parts of the project premises, along with information on matters that could impact dose modeling such as long-term erosion and potential changes in groundwater flow.

### 5.1.1 Applicable Requirements and Guidance

As explained in Section 1, certain areas of the project premises are being remediated in Phase 1 of the proposed decommissioning to NRC's unrestricted release criteria in 10 CFR 20.1402. These criteria state that a site will be considered acceptable for unrestricted use if the residual radioactivity that is distinguishable from background radiation results in a total effective dose equivalent to an average member of the critical group that does not exceed 25 mrem per year, including that from groundwater sources of drinking water, and the residual radioactivity has been reduced to levels that are ALARA.

NRC provides guidance (NRC 2006) on two approaches that may be used to determine that these unrestricted release criteria have been achieved:

(1) The dose modeling approach, which involves characterizing the site – after remediation, if necessary – and performing a dose assessment; and

(2) The DCGL and final status survey approach, which involves developing or using DCGLs and performing a final status survey to demonstrate that the DCGLs have been met.

NRC observes that the second option is usually the more efficient or simpler method and that these two approaches are not mutually exclusive; they are just different approaches to show that the potential dose from a remediated site is acceptable (NRC 2006).

As explained below, DOE is using the DCGL approach in Phase 1 of the proposed decommissioning and then, after remediation of subsurface soil in the two areas of interest, would perform dose modeling using Phase 1 final status survey data to estimate potential future doses from these areas assuming the rest of the project premises were to also be cleaned up to the unrestricted release criteria in 10 CFR 20.1402.

**DCGLs and Cleanup Goals**

DCGLs are radionuclide-specific concentration limits used during decommissioning to achieve the regulatory dose standard that permit the release of the property and termination of the license. The DCGL applicable to the average concentration over a survey unit is called the $DCGL_W$ and the DCGL applicable to limited areas of elevated concentrations within a survey unit is called the $DCGL_{EMC}$ (NRC 2006). However, Phase 1 of the decommissioning would not result in the release of any property or in termination of the NRC license for the site. As explained below, cleanup goals below the DCGLs are used to ensure that Phase 1 criteria do not limit Phase 2 options.

### 5.1.2 Context for DCGL Development

Figure 5-1 shows the areas of interest for surface soil, subsurface soil, and streambed sediment for which separate DCGLs have been developed. Each of these areas is discussed below.

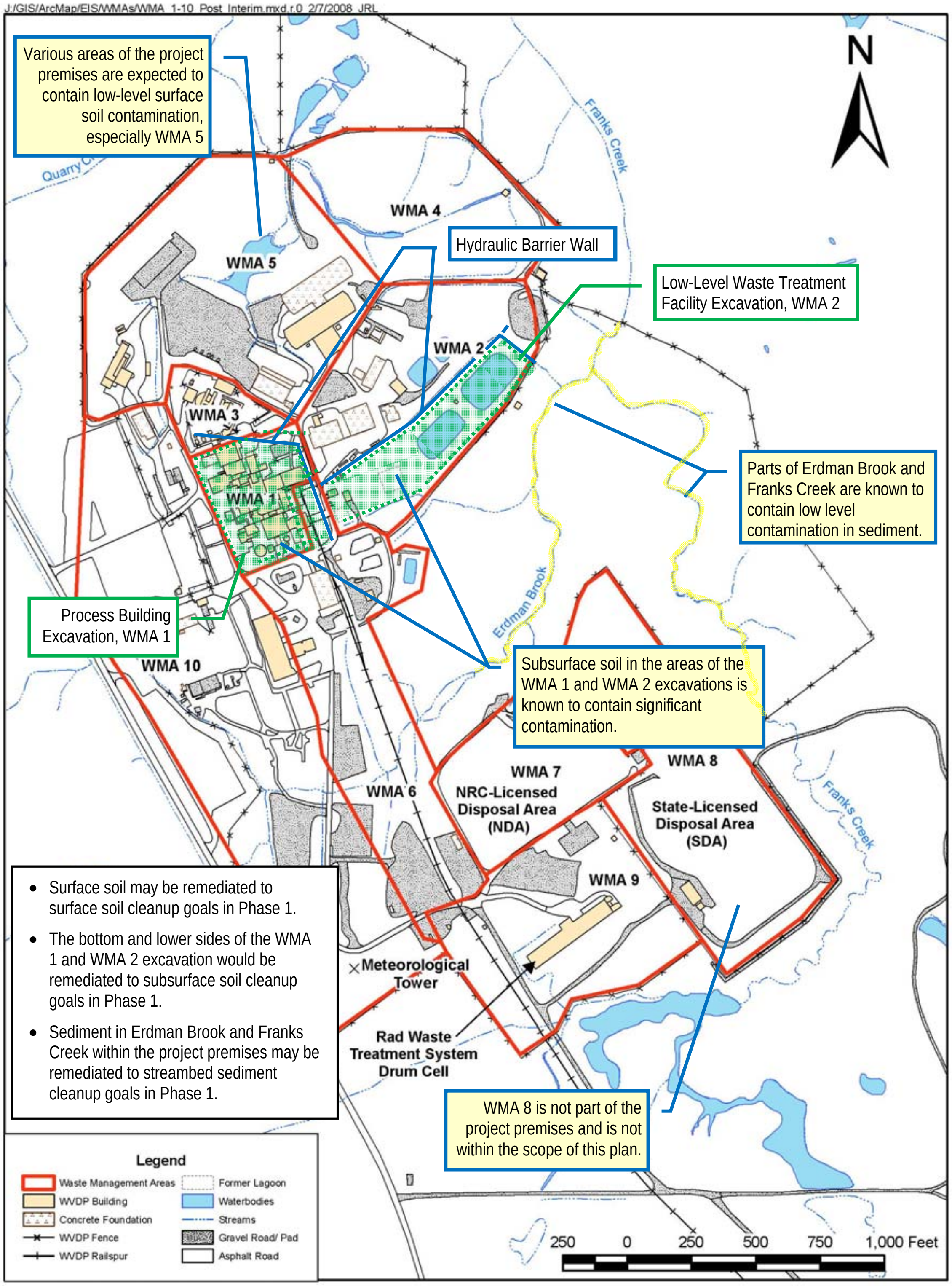



**Figure 5-1. Areas of Interest – Surface Soil, Subsurface Soil, and Streambed Sediment Within the Project Premises**

### Surface Soil

As explained in Section 1 of this plan, surface soil and sediment in drainage ditches on the project premises would be characterized for radioactivity early in Phase 1 to better define the nature and extent of radioactive contamination. Section 4.2 summarizes available data on radioactivity in these environmental media. Available data indicate that radioactive contamination is present in some areas but the magnitude and areal extent of this contamination have not been fully defined. Figure 4-6 shows locations where soil and sediment is known to have radioactivity concentrations in excess of background.

Cs-137 concentrations in excess of background have been measured in surface soil samples from all waste management areas (WMAs) where samples have been collected, with the highest measured concentration being 280 pCi/g. Sr-90 concentrations above background have been measured in surface soil samples from several WMAs, with a maximum of 12 pCi/g. Data on other radionuclides in surface soil are very limited, but above-background concentrations of Pu-238, Pu-239/240, and Am-241 have been identified as indicated in Section 4.2.

DCGLs for surface soil based on the unrestricted criteria in 10 CFR 20.1402 serve two purposes:

- They would support remediation of surface soil on selected portions of the project premises in Phase 1 of the proposed decommissioning if this plan were to be revised to provide for such remediation, and
- They would support decision-making for Phase 2 of the decommissioning.

### Subsurface Soil

The subsurface soil DCGLs, which are also based on the unrestricted release criteria of 10 CFR 20.1402, apply only to the bottoms and lower sides of the two large excavations to be dug to remove facilities in WMA 1 and WMA 2.[1] Figure 5-2 shows a conceptual cross section view of the planned WMA 1 excavation with representative data on Sr-90 concentrations. Figure 5-3 shows a conceptual cross section view of the planned WMA 2 excavation with representative data. Both excavations would extend one foot or more into the Lavery till, as indicated in Section 7.

As explained in Section 1 and detailed in Section 7, the Process Building and the other facilities in WMA 1 would be completely removed during Phase 1 of the proposed decommissioning, along with the source area of the north plateau groundwater plume. The excavation for this purpose would be approximately 2.8 acres in size and extend more than 40 feet below the ground into the top surface of the unweathered Lavery till. Figure 5-1 shows the approximate location of this excavation.

[1] The subsurface soil DCGLs would be applied to the sides of these excavations at depths greater than three feet below the surface; the surface soil DCGLs would be applied to the portions of the excavation sides closer to the ground surface. Note that the sides of the excavations that are upgradient or cross-gradient (i.e., not hydraulically downgradient) of the contamination source are not expected to be contaminated.

These DCGLs may also be applicable to excavations made in Phase 2 of the decommissioning depending on the approach selected for Phase 2 and other factors if the conceptual model described in this section is representative of the Phase 2 conditions.

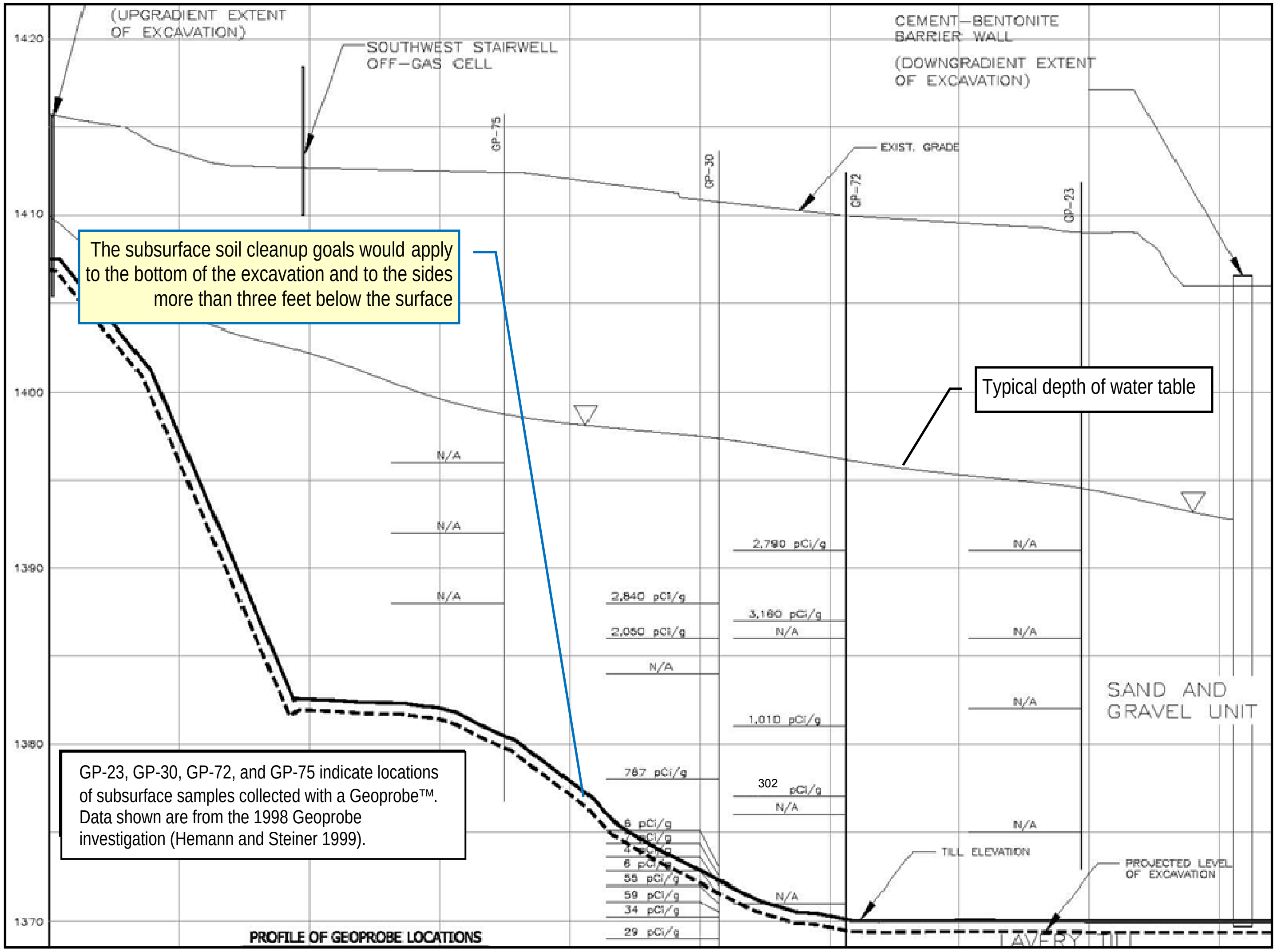



**Figure 5-2. Conceptual Cross Section View of WMA 1 Excavation With Representative Data on Sr-90 Concentrations**
(See Section 4.2 for more data and 7 for the excavation details.)

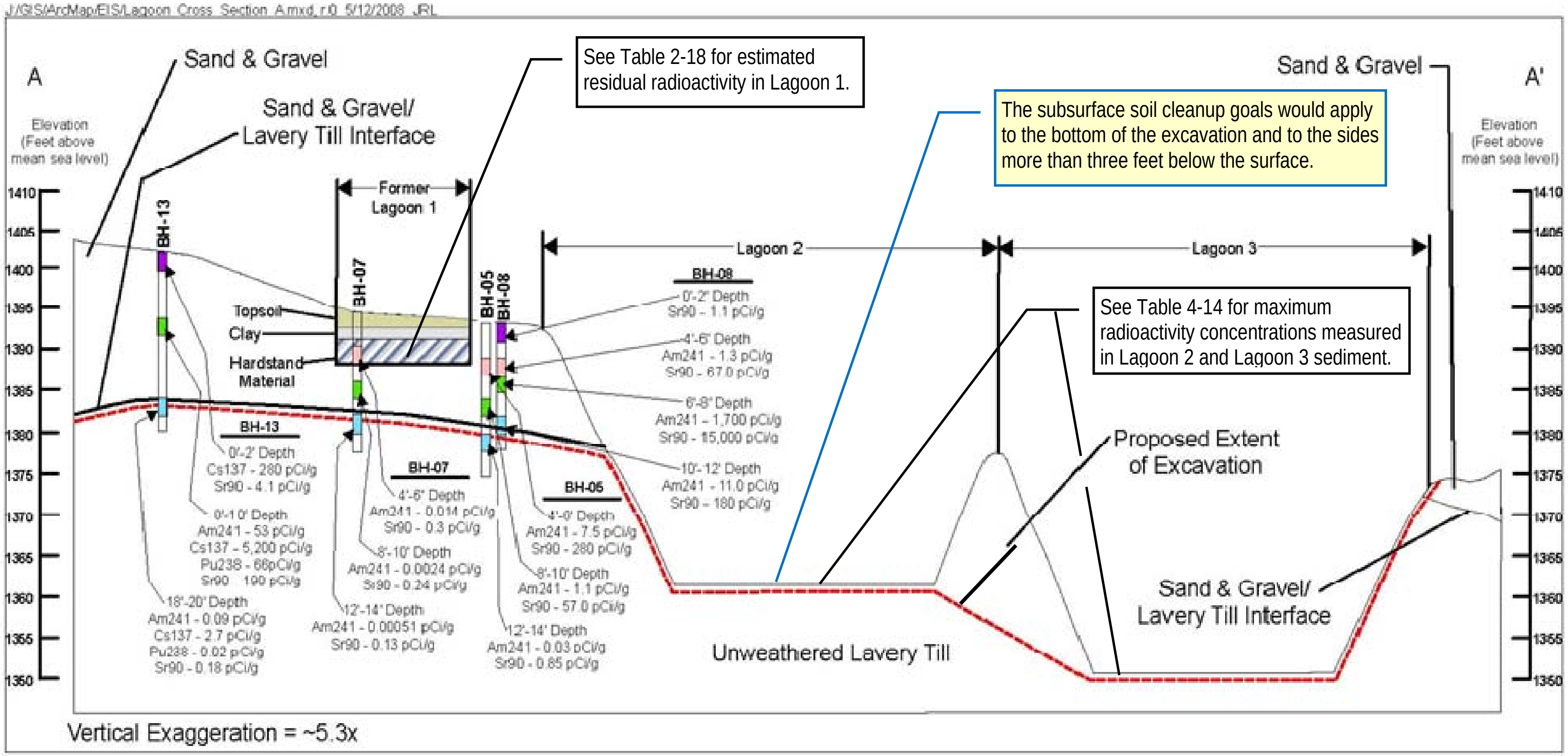



**Figure 5-3. Conceptual Cross Section View of WMA 2 Excavation With Representative Data on Subsurface Soil Contamination**
(See Section 4.2 for more data and 7 for excavation details. Analytical data shown are 1993 data from WVNSCO and D&M 1997.)

Available data on radioactive contamination in subsurface soil in WMA 1 described in Section 4.2 show Sr-90 to be the dominant radionuclide at depth. Figure 4-8 shows key data, which include three samples from several feet into the unweathered Lavery till that show Sr-90 concentrations of 13 pCi/g, 5.6 pCi/g, and 2.2 pCi/g at depths in the 35 to 40 feet range.

Other radionuclides with measured above-background concentrations in subsurface soil in WMA 1, with their maximum concentrations and the associated sample depth, include: Tc-99 (19 pCi/g at 19-23 feet), Cs-137 (31 pCi/g, at 27 to 29 feet), Pu-241 (15 pCi/g at 21 to 23 feet), and Am-241 (0.1 pCi/g, 19 to 23 feet). Table 5-1 shows the maximum measured radionuclide concentrations in the Lavery till in the areas of the large excavations in WMA 1 and WMA 2. Data in the Lavery till in these areas are limited – the complete set of data is provided in Table C-4 of Appendix C.

**Table 5-1. Measured Maximum Lavery Till Radionuclide Concentrations(1)**

| Nuclide | WMA 1 Excavation Area | | WMA 2 Excavation Area | |
|---|---|---|---|---|
| | Result (pCi/g) | Depth (ft) | Result (pCi/g)(3) | Depth (ft) |
| C-14 | <8.6E-02 | 40-42 | None | None |
| Sr-90 | 5.9E+01 | 38.5-39 | 8.5E-01(4) | 12-14 |
| Tc-99 | <2.6E-01 | 40-42 | None | None |
| I-129 | <2.3E-01 | 40-42 | None | None |
| Cs-137 | 2.6E-02 | 26-28 | 4.5E-01(4) | 12-14 |
| U-232 | <7.4E-03(2) | 36-38 | 1.2E-02(4) | 12-14 |
| U-233/234 | 1.6E-01 | 26-28 | 2.2E-01(5) | 12-14 |
| U-235 | <5.8E-03 | 26-28 | <6.6E-03(5) | 12-14 |
| U-238 | 1.1E-01 | 26-28 | 1.5E-01(5) | 12-14 |
| Pu-238 | <4.8E-03(2) | 36-38 | 1.0E-02(4) | 12-14 |
| Pu-239/240 | <4.8E-03(2) | 36-38 | <6.2E-03(5) | 12-14 |
| Pu-241 | 1.3E+00 | 26-28 | 9.5E-01(5) | 12-14 |
| Am-241 | <9.6E-03 | 26-28 | 3.0E-02(4) | 12-14 |

NOTES: (1) Data are from the 1993 RCRA facility investigation and the Geoprobe® studies described in Section 4. Data for C-14, Tc-99, and I-129 were taken from only one sample at location GP80-98.

(2) From location BH-21A shown in Figure 4-8.

(3) Higher concentrations were measured at location BH-08, but the BH-08 sample contained material from the sand and gravel layer as well as from the Lavery till. The location of this sample and BH-5 are shown in Figure 5-3.

(4) From the lowest sample collected at location BH-05, just below the surface of the Lavery till, as shown in Figure 5-3.

(5) From location BH-07 shown in Figure 5-3.

**Additional Characterization Planned**

The characterization program to be undertaken early in Phase 1 of the decommissioning as described in Section 9 would provide additional data on radioactivity in subsurface soil in WMA 1 and WMA 2 and lagoon sediment in WMA 2. As noted in Section 4, additional characterization measurements being taken in 2008 are expected to somewhat better define subsurface contamination in both areas.

The actual depth of the WMA 1 excavation would be based on removal of soil exceeding the subsurface soil cleanup goals, as explained in Section 7. The excavation would extend at least one foot into the Lavery till, as noted previously, and this is the point where the cleanup goals would apply. The configuration of the residual source would therefore be similar to the bottom of the excavation shown in the representative cross section in Figure 5-2.

Figure 5-1 also shows the approximate location of the major excavation in WMA 2. As explained in Section 1 and detailed in Section 7, a single excavation would be made to remove Lagoons, 1, 2, and 3, the interceptors, the Neutralization Pit, and the Solvent Dike. The area of this excavation would be approximately 4.2 acres and its depth would vary from approximately 12 feet on the southwest end to approximately 26 feet on the northeast end.[2]

Figure 5-3 shows a conceptual cross section of the WMA 2 excavation. This figure also shows representative data on subsurface radioactivity. As indicated on the figure, Table 2-18 provides an estimate of residual radioactivity in Lagoon 1 and Table 4-14 shows maximum radionuclide concentrations measured in sediment in Lagoon 2 and Lagoon 3.

As indicated in order-of-magnitude estimates in Table 2-18, Cs-137 (at 510 curies) is expected to dominate the radioactivity in Lagoon 1. Other radionuclides expected to be present include Pu-241 (134 curies), Sr-90 (17 curies), and Pu-238 (6.4 curies). Table 4-14 shows significant concentrations of Sr-90, Cs-137, Pu-238, Pu-239/240, and Am-241 in Lagoon 2 sediment and lower concentrations of these radionuclides in Lagoon 3 sediment.

The actual depth of the WMA 2 excavation would be based on removal of soil exceeding the subsurface soil cleanup goals, as explained in Section 7. The excavation would extend at least one foot into the Lavery till or, in the cases of Lagoon 2 and Lagoon 3, approximately two feet below the bottom the lagoons, which extend into the Lavery till. The configuration of the residual source would therefore be similar to the bottom of the excavation shown in the representative cross section in Figure 5-3.

While the subsurface soil cleanup goals serve as the remediation criteria for the two excavations as specified in Section 7, actual residual contamination levels in the Lavery till are expected to be well below these criteria. The concentrations of Sr-90 and Cs-137 are expected to be of the same order of magnitude as the lower surface soil cleanup goals.

[2] The 26-foot estimate is based on using the ground surface adjacent to Lagoon 3 as a reference point. The excavation is expected to extend several feet below the bottoms of Lagoons 2 and 3 to remove sediment with radioactivity concentrations above DCGLs.

This conclusion is based on contamination data shown in Table 5-1 and the relative impermeability of the Lavery till to radionuclide migration compared to the sand and gravel layer above it.

**Streambed Sediment**

Streambed sediment refers only to sediment in Erdman Brook and the portion of Franks Creek running through the project premises. Surface soil DCGLs would be applied to sediment in ditches and in other parts of the project premises, with the subsurface DCGLs being applied to the bottom of Lagoons 2 and 3. Unique DCGLs are appropriate for Erdman Brook and Franks Creek because the areas of these streams would not support farming or grazing of livestock as would other areas of the project premises, owing to the steep stream banks.

Section 4.2 summarizes the limited available data on radioactivity in the sediment of Erdman Brook and the portion of Franks Creek on the project premises. Figure 4-6 shows sample locations, with five in Erdman Brook and four in Franks Creek. Table 4-22 shows the highest measured concentrations of Cs-137 and other radionuclides. The highest measured Cs-137 concentration was 100 pCi/g and the highest Sr-90 concentration was 10 pCi/g. Section 4.2 describes a hot spot found in Erdman Brook in 1990 with a gamma radiation level of 3000 μR/h; a sample collected at that location showed 10,000 pCi/g Cs-137. The characterization program to be undertaken early in Phase 1 would provide additional data in radioactivity in the sediment of the two streams.

DCGLs for streambed sediment based on the unrestricted use criteria in 10 CFR 20.1402, like the surface soil DCGLs, serve two purposes:

- They would support remediation of contaminated sediment in Erdman Brook and the portion of Franks Creek on the project premises in Phase 1 of the proposed decommissioning if this plan were to be revised to provide for such remediation, and
- They would support decision-making for Phase 2 of the decommissioning.

### 5.1.3 Context for the Integrated Dose Assessment

Three sets of DCGLs have been developed as described in Section 5.2 to be applied to the particular areas of interest, that is:

- Surface soil DCGLs for surface soil and sediment in drainage ditches on the project premises (except for the sediment in Erdman Brook and Franks Creek), and for the sides of the WMA 1 and WMA 2 excavations from the ground surface to three feet below the surface;
- Subsurface soil DCGLs for the bottoms of the WMA 1 and WMA 2 excavations and for the excavation sides more than three feet below the ground surface; and
- Streambed sediment DCGLs for sediment in Erdman Brook and the portion of Franks Creek on the project premises.

Each set of DCGLs was developed as if the area of interest remediated to the applicable DCGLs were the only area to which a hypothetical future resident or recreationist might be exposed. However, it is more likely that a variety of receptors would be exposed to multiple sources under a range of land use scenarios. Considering each source independently allows for flexibility in subsequent combined dose evaluations, as discussed further in Section 5.3.

**Phase 1 and Phase 2 Sources**

Inherent in the proposed phased decision-making approach is the concept of Phase 1 and Phase 2 sources. Figure 5-4 identifies these different sources.

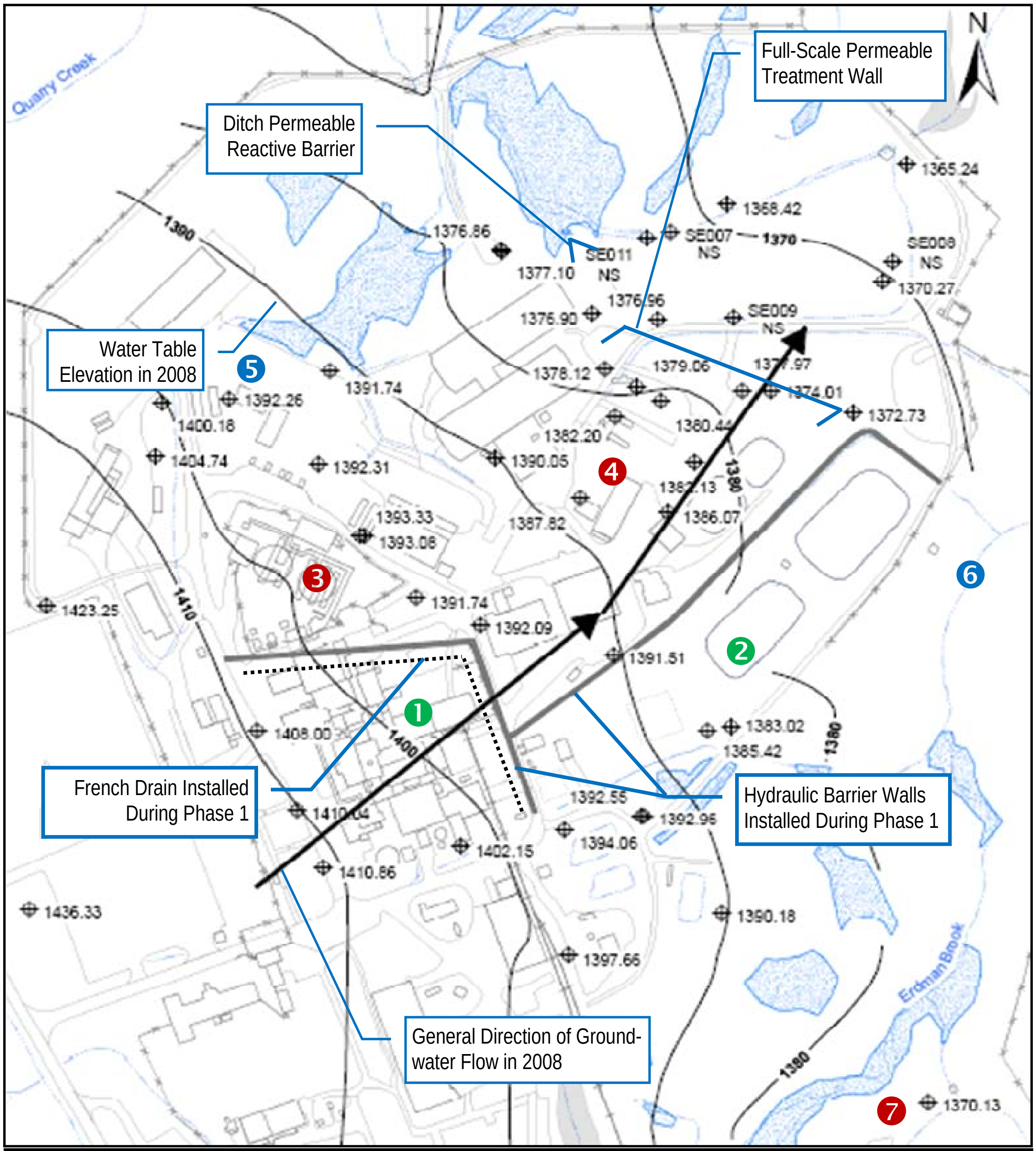
Phase 1 sources are those to be remediated during Phase 1 of the proposed decommissioning: mainly the WMA 1 area and the area in WMA 2 to be excavated. The surface soil and streambed sediment sources within the project premises may or may not be remediated in Phase 1[3]. Based on current characterization data, the main Phase 2 sources are the non-source area of the north plateau groundwater plume in WMA 2, WMA 4, and WMA 5; the Waste Tank Farm in WMA 3, and the NRC-Licensed Disposal Area (NDA) in WMA 7.

The table at the bottom of the Figure 5-4 shows the approximate amounts of total radioactivity in the different source areas based on estimates provided in Section 4. In this illustration, the remediated WMA 1 and WMA 2 excavated areas are the Phase 1 sources. The Waste Tank Farm, the non-source area of the north plateau groundwater plume, and the NDA are the Phase 2 sources. Low-level contamination in surface soil and streambed sediment – which may or may not be remediated during Phase 1 – could be either be a Phase 1 (remediated) or Phase 2 (remediated or not) source, with the potential impact from these sources much smaller than for the others.

Figure 5-4 shows other features of the project premises at the conclusion of the Phase 1 proposed decommissioning activities that could potentially influence future doses from residual radioactivity on the project premises:

- Groundwater flow, with the water table in the sand and gravel unit on the north plateau, with elevations expressed in feet above mean sea level, and the current pre-remediation general direction of groundwater illustrated on the figure;
- The two north plateau groundwater plume control measures to be installed before Phase 1 of the proposed decommissioning begins, the full-scale Permeable Treatment Wall and the Permeable Reactive Barrier; and
- The hydraulic barrier walls to be installed during Phase 1 of the proposed decommissioning as described in Section 7 and the French drain to be emplaced upgradient of the WMA 1 hydraulic barrier wall.

[3] As noted in Section 1, surface soil and sediment are to be remediated only in the Process Building-Vitrification Facility and Low-Level Waste Treatment Facility excavation areas during the proposed Phase 1 decommissioning activities. Soil and sediment in other areas may be remediated in Phase 1 by revision to this plan.




| No. | Source | Nature |
|---|---|---|
| 1 | WMA 1 excavation | Area 30-45 ft. below grade remediated below subsurface DCGLs for unrestricted release |
| 2 | WMA 2 excavation | Area 12-26 ft. below grade remediated below subsurface DCGLs for unrestricted release |
| 3 | Waste Tank Farm | Underground tanks with ~345,000 curies in 2011 |
| 4 | North plateau plume | Contaminated subsurface soil and groundwater, ~40 curies Sr-90 in 2041 |
| 5 | Surface soil | Low-level contamination in some areas, may be remediated below DCGLs |
| 6 | Streambeds | Low-level contamination, especially Cs-137, may be remediated below DCGLs |
| 7 | NDA | NRC-Licensed Disposal Area buried waste containing ~180,000 curies in 2011 |

**Figure 5-4. Sources at the Conclusion of Phase 1 of the Proposed Decommissioning**

The effectiveness of these features impacts potential future doses to the receptor and overall contribution to the evaluation of combined dose from all sources.

**Potential Conditions at the Conclusion of the WVDP Proposed Decommissioning**

To determine whether criteria used in Phase 1 proposed remediation activities could potentially limit the decommissioning options for Phase 2 of the decommissioning, consideration must be given to potential approaches to Phase 2. The Decommissioning EIS evaluates a range of closure alternatives. Two of these alternatives would provide bounding conditions for assessment of whether the criteria used for Phase 1 remediation activities could limit Phase 2 options:

- The site-wide close-in place-alternative, where the major facilities would be closed in place, with residual radioactivity in the Waste Tank Farm and the NDA being isolated by engineered barriers and the non-source areas of the north plateau groundwater plume being allowed to decay in place; and
- The site-wide removal alternative, where the Phase 2 sources would be removed and the entire site remediated to the unrestricted release criteria of 10 CFR 20.1402.

**Compatibility of Phase 1 Remediation With the Site-Wide Close-In-Place Alternative**

With the site-wide close-in place-alternative, the Phase 2 source areas would remain under NRC license. With Phase 1 of the decommissioning being accomplished as proposed, the contamination remaining in the WMA 1 and WMA 2 excavations would be residual radioactivity at concentrations below the subsurface soil DCGLs located far below the surface and covered with uncontaminated earth.

Under a site-wide close-in-place approach, the remediated Phase 1 areas would be expected to fall within the controlled licensed area because of their close proximity to the Phase 2 source areas. In view of this situation, the proposed remediation of the Phase 1 areas to unrestricted release standards would clearly be compatible with the Phase 2 source areas remaining under license. That is, remediation of the Phase 1 source areas as planned would have no impact on the site-wide close-in place-alternative and would not limit its implementation in any way.

**Compatibility of Phase 1 Remediation With the Site-Wide Removal Alternative**

Under the site-wide removal alternative, the Phase 2 source areas would be remediated to unrestricted release standards like the Phase 1 source areas. All of the associated radioactive waste would be disposed of offsite. However, while the remediation standards would be the same, the critical group for potential future exposures would not be the same for all parts of the site. Because remediation to unrestricted release standards under Phase 1 of the proposed decommissioning does not preclude achievement of unrestricted release standards under Phase 2, all remedial options may be considered.

However, this situation requires consideration of potential exposures to members of the different critical groups, a matter which is addressed below.

| Critical Group |
| --- |
| *Critical Group* means the group of individuals reasonably expected to receive the greatest exposure to residual radioactivity for any applicable set of circumstances (10 CFR 20.1003). |

Section 5.2 describes the critical groups for development of the different DCGLs. The average member of the critical group for development of the surface soil and subsurface soil DCGLs is a resident farmer. The average member of the critical group for development of the streambed sediment DCGLs is a recreationist, that is, a person who would spend time in the Erdman Brook and Franks Creek areas engaged in activities such as fishing and hiking.

One reasonably foreseeable set of circumstances would involve a person engaged in farming at some time in the future on one part of the remediated project premises who also spends time fishing and hiking at Erdman Brook and Franks Creek. This scenario would involve an individual being exposed to two different remediated source areas and being a member of the two different critical groups. Because this scenario is not considered in development of the DCGLs for the different areas of interest, it would be appropriate to consider whether it could result in such a hypothetical individual exceeding the unrestricted dose limit, that is, 25 mrem in one year, and whether the residual radioactivity has actually been reduced to levels that are ALARA in accordance with 10 CFR 20.1402.

Considering the foregoing discussion, Section 5.3 evaluates the potential impacts of this set of circumstance (combined sources of dose to receptor) on the DCGLs and the associated cleanup goals to be used to guide remediation during Phase 1 of the proposed decommissioning.

Two other factors that could potentially affect potential future doses from the remediated Phase 1 areas would be long-term erosion and potential changes in groundwater flow.

### 5.1.4 Potential Impact of Long-Term Erosion

The potential impact of long-term erosion is a consideration in development of DCGLs for Phase 1 of the proposed decommissioning and for estimating potential future doses from different parts of the project premises assuming that the entire site would be remediated for unrestricted use.

Section 3.5.3 of this plan describes the site geomorphology, including erosion processes such as channel incision, slope movement, and gully formation. Table 3-13 provides information on site erosion rates from various sources.

Detailed erosion studies performed in support of the Decommissioning EIS are described in Appendix F to that document. This appendix describes past studies and recent analyses that made use of two different landscape evolution models, SIBERIA and CHILD. The SIBERIA model is a physically based model that uses average precipitation over a specified timeframe and accounts for both fluvial and diffusional processes that move sediment through a drainage system (Willgoose 2000). The CHILD model performs simulations like the SIBERIA model but incorporates additional features. Both models were calibrated for the site.

Analyses using these models were performed to predict erosion rates at the WVDP over a 10,000-year time period. The two models predicted a total erosion depth on the central portion of the north plateau generally no greater than 3.2 feet, with the assumption of no climate change over the evaluation period. This rate would amount to about four inches over a 1000-year period.

Limited field data showing actual sheet and rill erosion rates are available as indicated in Table 3-13. The maximum measured erosion among 19 measurements over an 11-year period ending in 2001 was 0.04 feet (approximately 0.5 inch) on the slope of a gully. One spot south of Lagoon 2 showed buildup of 0.04 feet (about 0.5 inch) during that period.

Conclusions that can be drawn from the available field data and the erosion studies detailed in Appendix F of the Decommissioning EIS include:

- The central portion of the north plateau is expected to be generally stable over the next 1000 years;
- The WMA 2 area, which is near the Erdman Brook stream valley, is more susceptible to erosion than the WMA 1 area;
- Existing gullies will propagate, becoming deeper and longer, and new gullies will form, mainly on the edges of the north plateau, if erosion is unchecked;
- Rim widening and channel downcutting could occur in Erdman Brook and Franks Creek;
- With unmitigated erosion, gullies could eventually extend into the areas of Lagoons 1, 2, and 3 during the 1000-year evaluation period; and
- With unmitigated erosion, rim widening and downcutting of Erdman Brook could possibly impact the eastern edge of the areas of these lagoons, especially Lagoon 3.

### 5.1.5 Potential Changes in Groundwater Flow Fields

Changes in the groundwater flow pattern that might result from installation of the hydraulic barriers shown in Figure 5-1 could increase the potential for recontamination of the areas remediated in Phase 1. Groundwater in the sand and gravel unit on the north plateau currently flows northeast as indicated on Figure 5-4. With this flow pattern, and with the WMA 1 and WMA 2 hydraulic barriers remaining in place, the potential for transport of contaminants by groundwater into the WMA 1 and WMA 2 areas remediated during Phase 1 of the proposed decommissioning from Phase 2 source areas is low.

Appendix D describes the results of an analysis performed to evaluate groundwater flow conditions near these engineered barriers. This analysis suggests that the potential for recontamination of the remediated WMA 1 and WMA 2 areas would not be significantly increased with the engineered barriers in place.

### 5.1.6 Seepage of Groundwater

Figure 5-5 shows the locations of groundwater seeps on the north plateau. As can be seen in the figure, any groundwater from the seeps located on the project premises runs into Erdman Brook or Franks Creek. (Dames and Moore 1994)

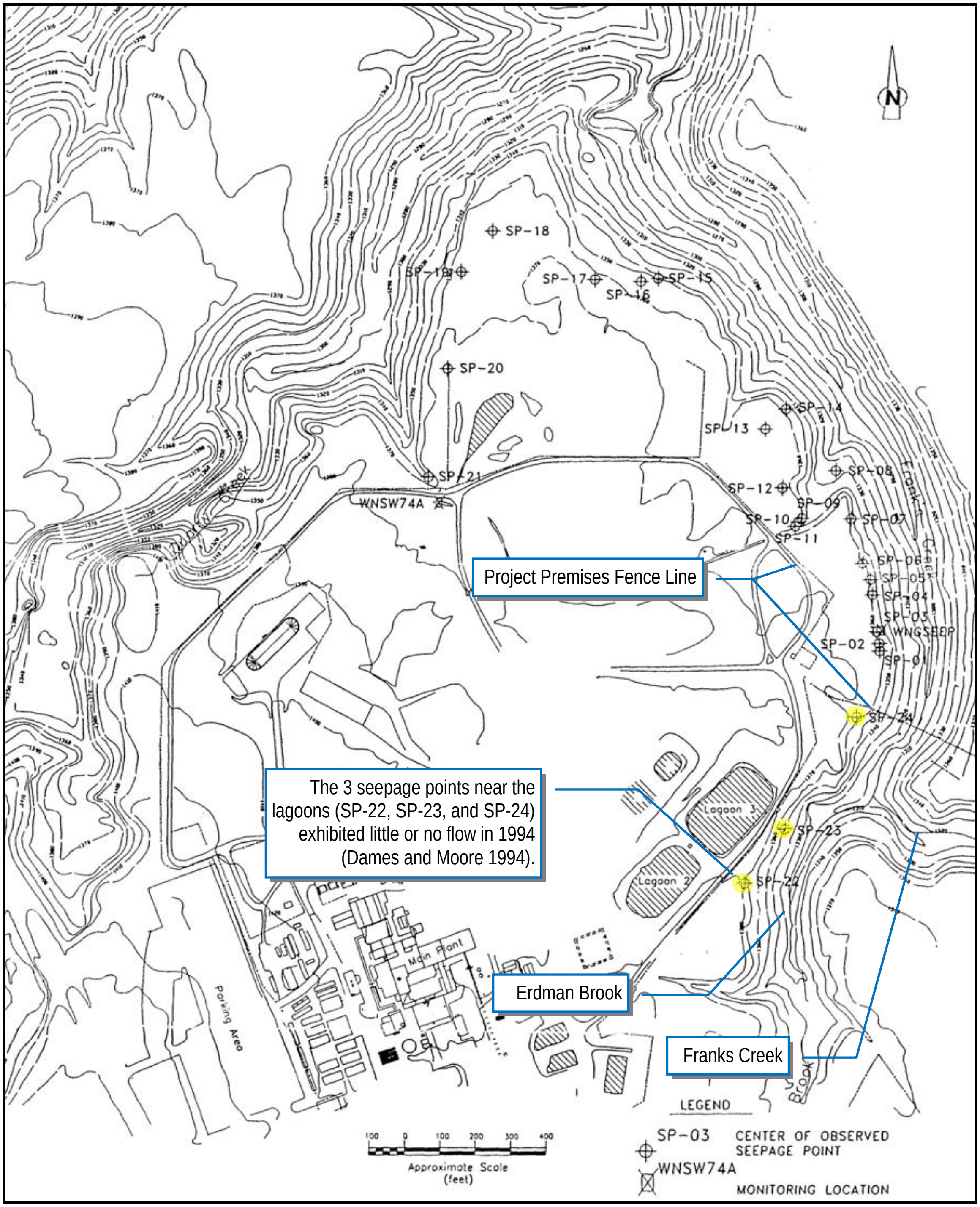



**Figure 5-5. Locations of Perimeter Seeps on the North Plateau** (From Dames and Moore 1994)

One other factor that could possibly affect conditions following Phase 1 of the proposed decommissioning is seepage of radioactively contaminated groundwater into Erdman Brook and Franks Creek.

As noted previously, surface soil and streambed sediment may be remediated during Phase 1 of the proposed decommissioning if this plan were to be revised to provide for these activities. The presence of groundwater seeps in the Erdman Brook area would be one factor taken into account in any decision to proceed with this remediation, since these seeps could possibly result in recontaminating the sediment in Erdman Brook.

However, the potential for significant radioactivity in seeps in this area following Phase 1 of the proposed decommissioning would be low due to the following factors:

- Any residual radioactivity that might remain in the Lavery till at the bottom of the remediated WMA 2 excavation would be at very low concentrations; and
- Groundwater flow changes with the Phase 1 vertical hydraulic barriers in place, as described in Appendix D, would be expected to substantially reduce the potential for contamination from the non-source area of the north plateau groundwater plume seeping into Erdman Brook.

Another factor that would be taken into account in any decision to proceed with remediation of sediment in Erdman Brook and in the portion of Franks Creek on the project premises during Phase 1 of the proposed decommissioning would be surface water runoff, especially runoff from the two radioactive waste disposal areas on the south plateau. Surface water runoff from both waste disposal sites is potentially contaminated due to surface soil contamination in these areas, although the potential impact on the streams is limited so long as the geomembrane covers for the waste disposal sites are intact.

### 5.1.7 Potential Impacts on the Kent Recessional Sequence

The potential for impacts on groundwater in the Kent Recessional Sequence from the any residual radioactivity that might remain in the bottom of the WMA 1 and WMA 2 excavated areas has been evaluated and found to be very low.

Groundwater in the sand and gravel unit generally flows to the northeast across the north plateau towards Franks Creek as shown in Figure 5-4. Water balance estimates (Yager 1987 and WVNSCO 1993a) suggest that approximately 60 percent of the groundwater from the sand and gravel unit discharges to Quarry Creek, Franks Creek, and Erdman Brook through surface water drainage discharge points and the groundwater seeps located along the margins of the north plateau that are shown in Figure 5-5.

Approximately two percent of the total discharge from the sand and gravel unit travels vertically downward to the underlying unweathered Lavery till, where groundwater flows vertically downward toward the underlying Kent Recessional Sequence at an average vertical groundwater velocity of 0.20 feet per year (WVNSCO 1993a). The unweathered Lavery till is approximately 30 to 45 feet thick below the planned WMA 1 excavation and 40 to 110 feet thick below the planned WMA 2 excavation (WVNSCO 1993b).

It would take approximately 200 years for groundwater to migrate through the unweathered Lavery till at WMA 1 and WMA 2 assuming a Lavery till thickness of 40 feet and an average groundwater velocity of 0.20 feet per year. Mobilization and migration of the residual radionuclide inventory at the bottom of the WMA 1 and WMA 2 excavations through the Lavery till groundwater pathway would take even longer considering the sorptive properties of the Lavery till.

Short-lived radionuclides (Sr-90, Cs-137, and Pu-241) will have decayed away during these time frames. The long-lived radionuclide inventory is not an issue as the residual concentrations within the Lavery till are expected to be comparable to background concentrations for surface soil. The residual radionuclide concentrations in the Lavery till in the bottom of the WMA 1 and WMA 2 excavations are expected to be lower than those reported in Table 5-1 and would therefore not significantly impact the Kent Recessional Sequence. Groundwater reaching the Kent Recessional Sequence flows laterally to the northeast at an average velocity of 0.40 feet per year and eventually discharges to Buttermilk Creek.

The potential for impacts on groundwater in Lavery till sand has also been considered.

The Lavery till sand is located 30 to 40 feet below grade within the Lavery till and is recharged by downward groundwater flow from the Lavery till. The Lavery till sand is located south of the WMA 1 excavation (Figure 3-64) and would not be impacted by the Phase 1 excavation of WMA 1.

However, the Lavery till sand underlies approximately 15,000 square feet of the southwestern most portion of WMA 2 near the Solvent Dike (Figure 3-64). The Solvent Dike was originally excavated in 1986 and would be excavated down into the Lavery till during the excavation of WMA 2. Because any residual radionuclide concentrations are expected to be less than those reported in Table 5-1, groundwater flow from the Lavery till would not significantly impact the Lavery till sand.

### 5.1.8 General Dose Modeling Process

The general process for the dose modeling described in Section 5.2 and 5.3 is illustrated in Figure 5-6. As indicated in the figure, the process involves the following major steps:

- Calculating the DCGLs,
- Performing parameter sensitivity analyses and refining the conceptual models and the DCGLs as appropriate based on the results,
- Analyzing a combined source area exposure scenario,
- Factoring in the results of the ALARA analysis described in Section 6,
- Establishing cleanup goals (target levels below the DCGLs) to ensure that the degree of remediation in Phase 1 of the proposed decommissioning would not limit Phase 2 options,
- Characterizing surface soil, subsurface soil, and streambed sediment early in Phase 1,

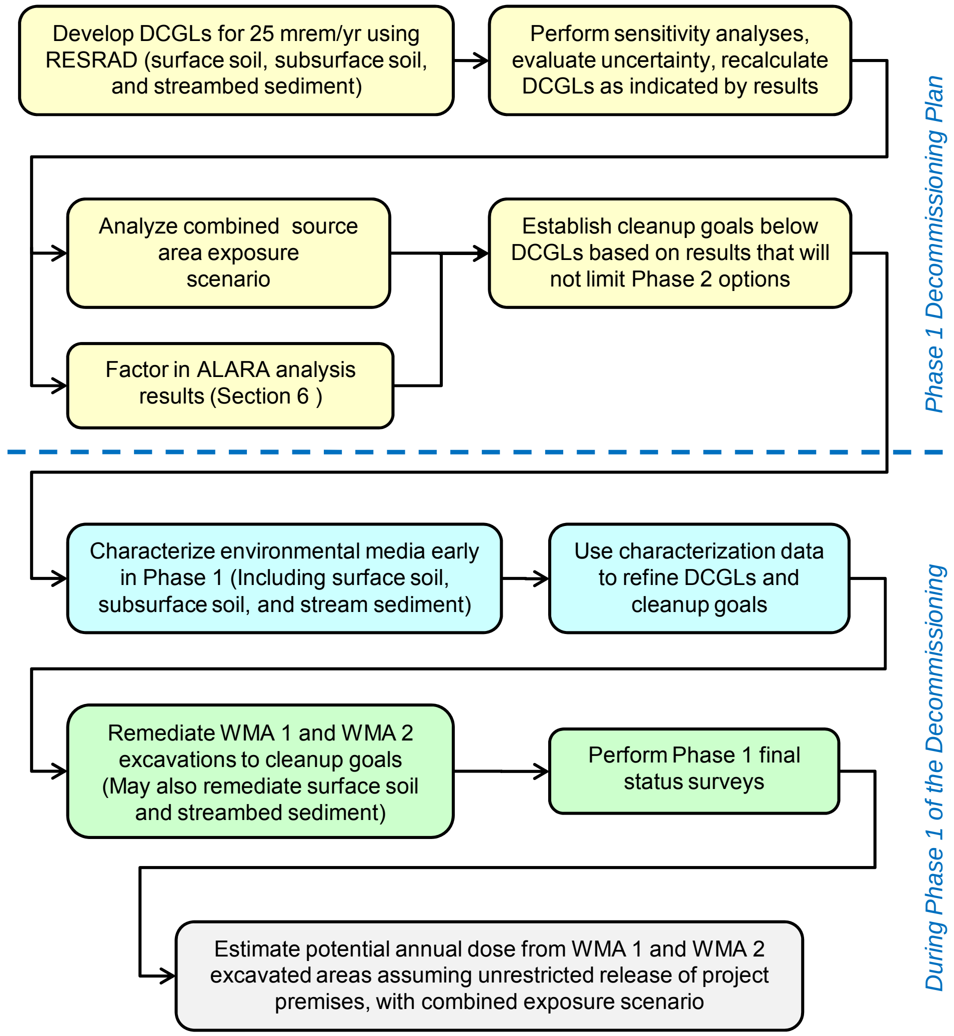



**Figure 5-6. General Dose Modeling Process**

- Refining the DCGLs and cleanup goals based on the resulting data[4],
- Completing remediation of the WMA 1 and WMA 2 excavations to the cleanup goals,
- Performing Phase 1 final status surveys in the remediated Phase 1 areas, and
- Making an estimate of the potential future doses for the remediated WMA 1 and WMA 2 areas using these data.

[4] The characterization to be performed early in Phase 1, which is described in Section 9, would provide data that may be useful in better defining source geometry in the conceptual model. For example, if the depth of surface soil contamination were to be found to typically be about six inches, rather than three feet (one meter) as used in the conceptual model, then the conceptual model thickness would be changed and the DCGLs recalculated. While DCGLs are developed for 18 radionuclides, characterization data may indicate that some radionuclides may be dropped from further consideration. This could be the case, for example, if one or more of the 18 radionuclides do not show up above the minimum detectable concentration in any of the soil or sediment samples.

Note that use of a surrogate radionuclide such as Cs-137 to represent all radionuclides in a mixture of radionuclides is not practical at this time because available data are not sufficient to establish radionuclide distributions in environmental media. This matter is discussed further in Section 5.4.3.

## 5.2 DCGL Development

This section describes the conceptual models used for developing DCGLs for surface soil, subsurface soil, and streambed sediment. It then describes the mathematical model (RESRAD) used to calculate these DCGLs and identifies the DCGLs. It concludes with a discussion of input parameter sensitivity and uncertainty.

The analyses simulate the behavior of residual radioactivity over 1000 years, a period during which peak annual doses from the radionuclides of primary interest would be expected to occur. DCGLs have been developed for residual radioactivity that would result in 25 mrem per year dose to the average member of the critical group for each of the following 18 radionuclides of interest:

| | | | | |
|---|---|---|---|---|
| Am-241 | Cs-137 | Pu-239 | Tc-99 | U-235 |
| C-14 | I-129 | Pu-240 | U-232 | U-238 |
| Cm-243 | Np-237 | Pu-241 | U-233 | |
| Cm-244 | Pu-238 | Sr-90 | U-234 | |

Early studies related to the long-term performance assessment for residual radioactivity at the site included consideration of the initial inventory of radionuclides received on site and their progeny. This list was screened to eliminate short-lived radionuclides and those radionuclides present in insignificant quantities. Thirty radionuclides of interest remained after this screening process. These radionuclides were important to worker dose and/or long-term dose from residual radioactivity.

In characterization of radionuclides in the area of the Process Building, the north plateau groundwater plume, and the lagoons, it was determined that 18 of the 30 radionuclides were important for the development of Phase 1 DCGLs. These radionuclides were selected based on screening of simplified groundwater release and intrusion scenarios for north and south plateau facilities. The screening indicated that other radionuclides would in combination contribute less than one per cent of potential dose impacts at the individual facility.

The list of radionuclides for which DCGLs are initially developed would be expanded if necessary following completion of soil and sediment characterization early in Phase 1 of the proposed decommissioning. If other radionuclides show up in concentrations significantly above the minimum detectable concentrations, additional DCGLs would be developed for these radionuclides and their progeny, as appropriate. Conversely, if any of the 18 radionuclides of interest fail to show up in concentrations above the minimum detectable concentrations, then they may be omitted from the final DCGLs for the Phase 1 actions.

As explained in Section 1, the DCGLs for Sr-90 and Cs-137 were developed to incorporate a 30-year decay period from 2011. That is, achieving residual radioactivity levels less than the DCGLs would ensure that dose criteria of 10 CFR 20.1402 would be met in 2041, around the time when the vitrified HLW canisters are expected to be shipped to the federal geologic repository.[5] Although a 30-year decay period could have been applied to all radionuclides, Sr-90 and Cs-137 were selected based on their prevalence in soil and sediment contamination, their expected peak doses at the onset of exposure, and the short half lives of these particular radionuclides.

### 5.2.1 Conceptual Models for DCGL Development

The conceptual model for development of surface soil DCGLs is described first.

**Surface Soil Conceptual Model**

Figure 5-7 illustrates the conceptual model for surface soil DCGL development. As is evident from this figure, which was adapted from the RESRAD Manual (Yu, et al. 2001), the basic RESRAD model is used.

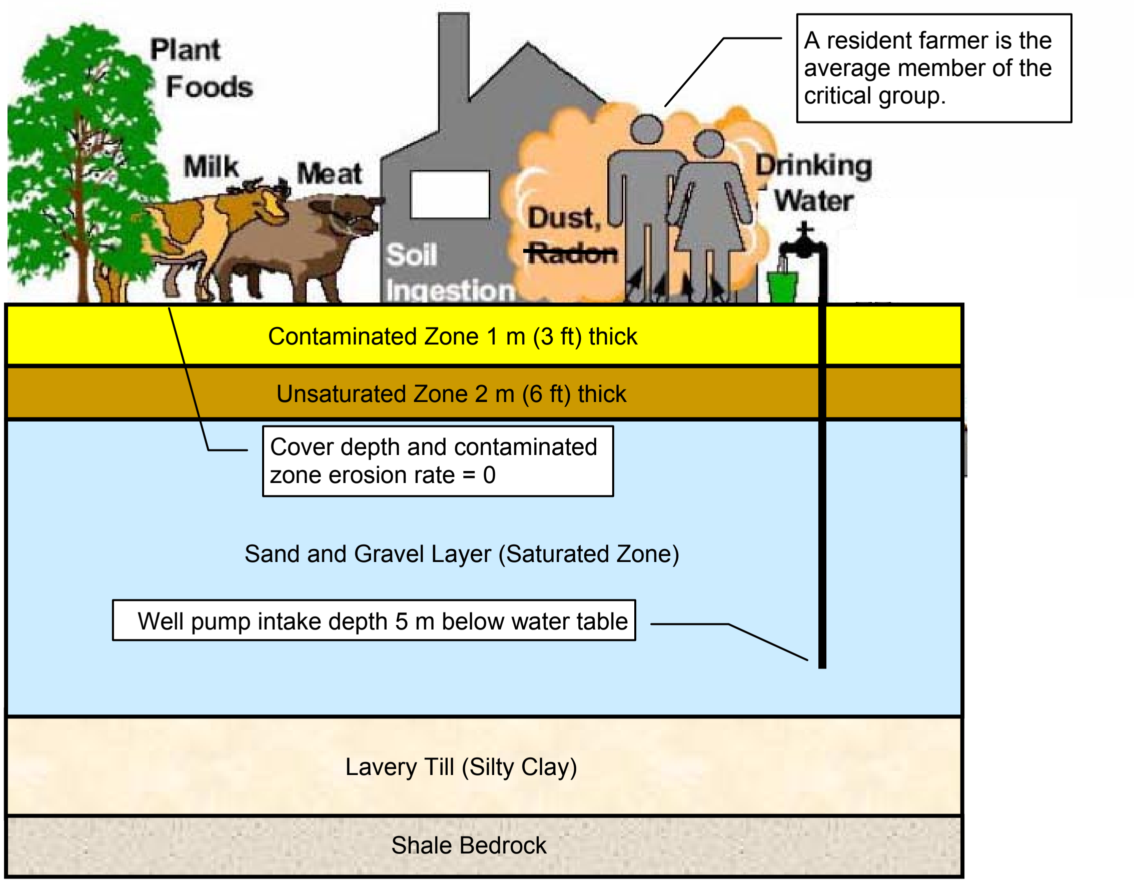



**Figure 5-7. Conceptual Model for Surface Soil DCGL Development**

[5] This approach would support any license termination actions that may take place in Phase 2 of the decommissioning, which could not be finalized before 2041 considering current expectations about shipment of the vitrified HLW canisters and the scope of effort necessary to achieve an unrestricted release of major portions of the project premises.

RESRAD is a computer model designed to estimate radiation doses and risks from RESidual RADioactive materials (Yu, et al. 2001). DOE Order 5400.5 designates RESRAD for the evaluation of radioactively contaminated sites, and NRC has approved the use of RESRAD for dose evaluation by licensees involved in decommissioning. RESRAD capabilities are discussed further in Section 5.2.2.

A resident farmer is the average member of the critical group for development of surface soil DCGLs. The hypothetical residence and farm are assumed to be located on a part of the project premises impacted solely by radioactivity in surface soil.

Other possible critical groups were considered. However, a resident farmer was determined to be most limiting because such an individual would be engaged in a wider range of activities that could result in greater exposure to residual radioactivity in surface soil than other critical groups considered.

The resident farmer would be impacted by a number of exposure pathways with long exposure durations. This hypothetical individual would utilize significant amounts of groundwater that involves consideration of secondary exposure pathways such as household water use, irrigation, and watering livestock. The resident farmer scenario also is consistent with current and projected future land uses for Cattaraugus County as discussed in Section 3.

Note that the geological units shown in Figure 5-7 are representative models of the north plateau as shown in Figure 3-6. Figure 3-7 shows that the geological units on the south plateau are different in that the sand and gravel unit does not extend to that area. However, DCGLs developed using the conceptual model illustrated in Figure 5-7 are appropriate for surface soil on the south plateau because the input parameters used in the modeling for the north plateau would generally be conservative for the south plateau. For example, site-specific distribution coefficients for the sand and gravel unit (where available) are typically lower than those for the Lavery till, and use of the lower values results in faster radionuclide movement though soil in the north plateau model, and less time for radioactive decay to take place.[6]

Table 5-2 shows the exposure pathways evaluated for development of the surface soil DCGLs.

**Table 5-2. Exposure Pathways for Surface Soil DCGL Development**

| Exposure Pathways | Active |
|---|---|
| External gamma radiation from contaminated soil | Yes |
| Inhalation (airborne radioactivity from re-suspended contaminated soil) | Yes |
| Plant ingestion (produce impacted by contaminated soil and groundwater sources) | Yes |
| Meat ingestion (beef impacted by contaminated soil and groundwater sources) | Yes |

[6] Table C-2 of Appendix C shows that site-specific $K_d$ values for neptunium, plutonium, and strontium in the sand and gravel unit are used in the surface soil model. Table 3-20 of Section 3 shows the basis for these values.

**Table 5-2. Exposure Pathways for Surface Soil DCGL Development**

| Exposure Pathways | Active |
|---|---|
| Milk ingestion (impacted by contaminated soil and groundwater sources) | Yes |
| Aquatic food ingestion | No(1) |
| Ingestion of drinking water (groundwater impacted by contaminated soil) | Yes |
| Ingestion of drinking water (from surface water)(2) | No |
| Soil ingestion (while farming and residing on contaminated soil) | Yes |
| Radon inhalation | No(3) |

NOTES: (1) Fish ingestion is considered in development of the streambed sediment DCGLs and in the combined scenario discussed in Section 5.3.

(2) Groundwater was assumed to be the source of all drinking water because the low flow volumes in Erdman Brook and Franks Creek could not support the resident farmer. Also, use of surface water would not be as conservative as groundwater since surface water is diluted by runoff from the entire watershed area. Incidental ingestion of water from the streams is evaluated in development of the streambed sediment DCGLs as shown in Table 5-6.

(3) For the standard resident farmer scenario, the radon pathway is not considered (Appendix J, NRC 2006).

RESRAD requires a variety of input parameter values to completely describe the conceptual model. All of the input parameters for development of the surface soil DCGLs appear in Appendix C. Table 5-3 identifies selected key input parameters.

**Table 5-3. Key Input Parameters for Surface Soil DCGL Development(1)**

| Parameter (Units) | Value | Basis |
|---|---|---|
| Area of contaminated zone ($m^2$) | 1.0E+04 | Necessary for subsistence farming. |
| Thickness of contaminated zone (m) | 1.0E+00 | Conservative assumption.(2) |
| Cover depth (m) | 0 | Contamination on surface. |
| Contaminated zone erosion rate (m/y) | 0 | Conservative assumption.(3) |
| Well pump intake depth below water table (m) | 5.0E+00 | Consistent with water table. |
| Well pumping rate ($m^3$/y) | 5.72E+03 | See Table C-2. |
| Unsaturated zone thickness (m) | 2.0E+00 | Typical for north plateau. |
| Distribution coefficient for strontium (mL/g) | 6.16E+00 | See Table C-2. |
| Distribution coefficient for cesium (mL/g) | 2.8E+02 | See Table C-2. |
| Distribution coefficient for americium (mL/g) | 1.9E+03 | See Table C-2. |

NOTES: (1) See Appendix C for other input parameters. Metric units are used here because they are normally used in RESRAD.

(2) Available data discussed in Sections 2.3.2 and 4.2 suggest that most contamination will be found within a few inches of the surface except where the north plateau groundwater plume has impacted subsurface soil.

(3) This assumption is conservative because it results in no depletion of the source through erosion.

Key features of this conceptual model and key assumptions include:

- The areal extent of surface soil contamination, which has not been well defined, can be represented by a distributed source spread over a relatively large area (10,000 square meters or approximately 2.5 acres);
- The average depth of contamination (contamination zone thickness) is approximately 3.3 feet (one meter), a conservative assumption for the site;
- All water use (e.g., household, crop irrigation, and livestock watering) is from contaminated groundwater;
- Adequate productivity from a well pumping from the aquifer would be available in the future to support a subsistence farm;
- Soil erosion (i.e., source depletion) does not occur over the 1,000-year modeling period;
- The non-dispersion groundwater model is used because of the large contaminated area consistent with applicable guidance (Yu, et al. 2001, Appendix E);
- The groundwater flow regime under the post-remedial conditions is unchanged from the current configuration (e.g. flow direction, aquifer productivity); and
- DCGLs that reflect 30 years of decay (i.e., apply to the year 2041) are appropriate for Sr-90 and Cs-137. Although a 30-year decay period could have been applied to all radionuclides, Sr-90 and Cs-137 were selected based on their prevalence in surface soil, their expected peak doses at the onset of exposure, and the short half lives of these particular radionuclides, as noted previously.

**Subsurface Soil Conceptual Model**

Figure 5-8 illustrates the conceptual model for subsurface soil DCGL development. The basic RESRAD model is used as with development of surface soil DCGLs, with a resident farmer being the average member of the critical group. The hypothetical residence and farm are assumed to be located in the remediated WMA 1 area. Exposure to the subsurface radioactivity occurs following intrusion and surface dispersal when installing a water collection cistern.

Other possible critical groups were considered as with the conceptual model for surface soil DCGLs. However, a resident farmer was determined to be most limiting because such an individual would be engaged in a wider range of activities that could result in greater exposure to residual radioactivity in subsurface soil than other critical groups considered.

Consideration was given to a home construction scenario with the basement in the hypothetical home extending 10 feet below the surface. However, this scenario was not considered to be plausible because any contaminated subsurface soil would be more than 10 feet below the surface in the remediated WMA 1 and WMA 2 areas (the bottoms of the excavations would be more than 10 feet below the surface and uncontaminated soil would be used to backfill the excavations).

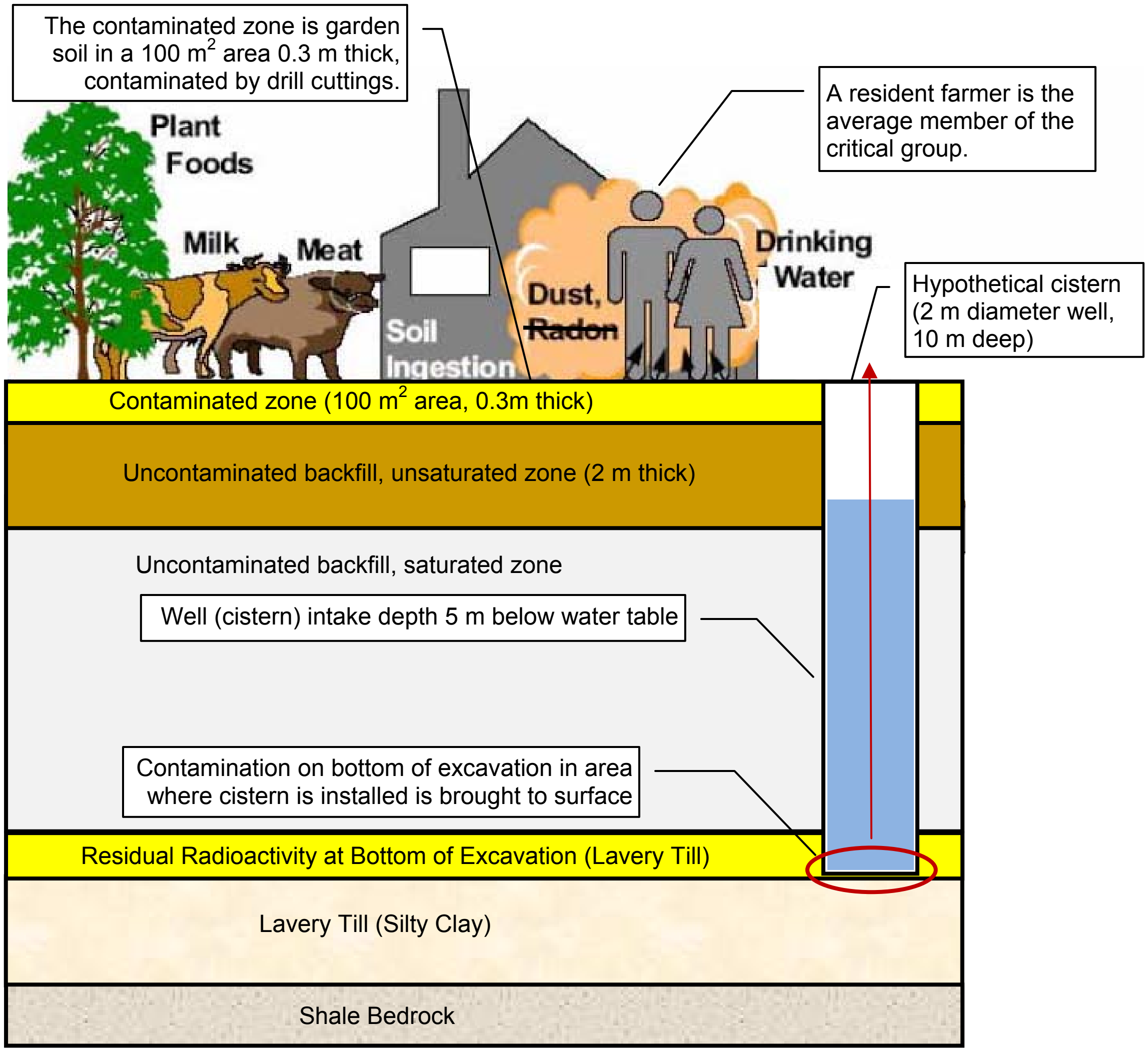



**Figure 5-8. Conceptual Model for Subsurface Soil DCGL Development**

Note that Section 7 specifies that the uncontaminated backfill as shown in the figure would be soil obtained from outside of the Center from an area that has not been impacted by site radioactivity. No soil removed during the excavation work would be used in filling the excavation, even if that soil were determined to be uncontaminated.

**Consideration of NRC Guidance Related to Buried Radioactivity**

Also considered in development of this conceptual model was NRC guidance related to assessment of buried radioactivity in Appendix J to NUREG-1757, Volume 2 (NRC 2006). This guidance applies to cases where radioactive material is buried deep enough that an external dose is not possible in its existing configuration; any radioactivity remaining at the bottom of the WMA 1 and WMA 2 excavations would meet this condition, and the WVDP situation is consistent with the intent of the guidance.

The NRC notes that a conservative analysis could be performed that assumes all of the material is spread on the surface. It describes two alternative exposure scenarios: (1) leaching of the radionuclides to groundwater, which is then used by a residential farmer, and (2) inadvertent intrusion into the buried radioactive material, with part of the radioactivity being spread across the surface where this fraction causes exposure to a resident farmer through various pathways. NRC further notes that

> "The second alternative exposure scenario encompasses all the exposure pathways and, although not all of the source term is in the original position, leaching will occur both from the remaining buried residual radioactivity (if there is any) and the surface soil. Unless differences in the thickness of the unsaturated zone will make a tremendous difference in travel time to the aquifer, the groundwater concentrations should be similar and, therefore, will generally result in higher doses than the first alternate scenario."

The surface soil DCGLs discussed previously represent the case where all of the radioactive material of interest is located on the surface; as explained in Section 6, possible application of these DCGLs to the subsurface soil of interest would be addressed in the ALARA analysis. DOE has selected the second alternative exposure scenario – inadvertent intrusion into the buried material, that is, into any residual radioactivity at the bottom of the WMA 1 and WMA 2 excavations – as the basis for development of the subsurface soil DCGLs. NRC discusses in Appendix J to NUREG-1757 (NRC 2006) the use of RESRAD in analysis of the inadvertent intrusion scenario, which DOE has implemented here.

This conceptual model has the following features, some of which are indicated on Figure 5-8:

- The initial modeled source of contamination brought to the surface consists of residual radioactivity in an area two meters (about six feet) in diameter and one meter (about three feet) thick, the top surface of which lies nine meters (about 30 feet) below the ground surface. The contamination assumed to be in this volume of subsurface soil represents the residual radioactivity of interest at the bottom of the WMA 1 or WMA 2 excavation. The exposure occurs when the subsurface radioactivity is deposited on the ground surface where it can result in exposure to members of the critical group through various pathways.

- For conservatism the hypothetical well is assumed to have a large diameter representative of a cistern, rather than the smaller diameter of a typical water supply well (eight inches). The larger diameter provides for a greater volume of contamination being brought to the surface, and is therefore conservative compared to the typical well diameter.
- The nine meters (about 30 feet) of uncontaminated backfill above the initial source of contamination comingles with the contaminated soil, and the mixture is assumed to uniformly cover a cultivated garden area of 100 square meters (about 1000 square feet), i.e., a small portion of the 10,000 square meter garden, to a depth of 0.3 meter (one foot).[7]
- The remainder of the contamination in the bottom of the excavation was not modeled as a continuing source to groundwater because this source is located below the assumed well pump intake depth and would not be expected to leach upward into the source of water available to the resident farmer. The potential dose contribution from this source has been determined to be small compared to the potential dose from contamination brought to the surface during installation of the hypothetical cistern. This matter is discussed further in Section 5.2.4.

Table 5-4 shows the exposure pathways for development of the subsurface soil DCGLs, which are the same as for the surface soil DCGLs.

**Table 5-4. Exposure Pathways for Subsurface Soil DCGL Development**

| Exposure Pathways | Active |
|---|---|
| External gamma radiation from contaminated soil | Yes |
| Inhalation of airborne radioactivity from re-suspended contaminated soil | Yes |
| Plant ingestion (produce impacted by contaminated soil and groundwater contaminated by impacted soil) | Yes |
| Meat ingestion (beef impacted by contaminated soil and groundwater contaminated by impacted soil) | Yes |
| Milk ingestion (impacted by contaminated soil and groundwater contaminated by impacted soil) | Yes |
| Aquatic food ingestion | No(1) |
| Ingestion of drinking water (from groundwater contaminated by impacted soil) | Yes |
| Ingestion of drinking water (from surface water)(2) | No |
| Soil ingestion | Yes |
| Radon inhalation | No(3) |

NOTES: (1) Fish ingestion is considered in development of the streambed sediment DCGLs and in the combined scenario discussed in Section 5.3.

(2) Groundwater was assumed to be the source of all drinking water because the low flow volumes in Erdman Brook and Franks Creek could not support the resident farmer. Use of surface water would also not be as conservative as groundwater since surface water is diluted by runoff from the entire

[7] Consideration was given to using a contaminated area larger than 100 square meters for the hypothetical garden. If the material brought to the surface during installation of the hypothetical cistern were spread over an area of 1000 square meters, for example, it would extend to an average depth of only about three centimeters (1.2 inches). If sufficient material were brought to the surface to cover 1,000 square meters to a depth of 0.3 meter (one foot), DCGLs would be reduced by a factor similar to that observed for surface soil DCGLs (reduction factors ranged from 1.3 for Cs-137 to 28 for C-14, see Appendix C).

watershed area. Incidental ingestion of water from the streams is evaluated in development of the streambed sediment DCGLs as shown in Table 5-6.

(3) In using the standard resident farmer scenario in modeling of buried radioactivity, the radon pathway is not considered (Appendix J, NRC 2006).

All of the input parameters for development of the subsurface soil DCGLs appear in Appendix C. Table 5-5 identifies selected key input parameters.

**Table 5-5. Key Input Parameters for Subsurface Soil DCGL Development**(1)

| Parameter (Units) | Value | Basis |
|---|---|---|
| Initial source - cistern diameter (m) | 2.0E+00 | Conservative values used to estimate radioactivity brought to the surface to be mixed in garden soil. |
| Initial source – depth below surface (m) | 9.0E+00 | |
| Initial source – thickness (m) | 1.0E+00 | |
| Area of contaminated zone ($m^2$) | 1.0E+02 | Area drill cuttings from cistern installation spread on surface. |
| Thickness of contaminated zone (m) | 3.0E-01 | Contaminated soil depth in garden. |
| Cover depth (m) | 0 | Contamination on surface. |
| Contaminated zone erosion rate (m/y) | 0 | Conservative assumption.(2) |
| Well pumping rate ($m^3$/y) | 5.72E+03 | See Table C-2. |
| Unsaturated zone thickness (m) | 2.0E+00 | Reasonable for WMA 1 and WMA 2. |
| Distribution coefficient for strontium (mL/g) | 1.5E+01 | See Table C-2. |
| Distribution coefficient for cesium (mL/g) | 4.8E+02 | See Table C-2. |
| Distribution coefficient for americium (mL/g) | 4.0E+03 | See Table C-2. |

NOTES: (1) See Appendix C for other input parameters. Metric units are used here because they are normally used in RESRAD.

(2) This assumption is conservative because it results in no depletion of the source.

Key assumptions associated with this conceptual model include:

- Contamination in the bottom one meter of the 10 meter deep excavation of the two meter diameter cistern would be brought to the surface, along with the overlying uncontaminated backfill, and blended into the soil over a 100 square meter area used by the resident farmer.
- All water used by the resident farmer (e.g., household, crop irrigation, and livestock watering) is groundwater which has been impacted by leaching of contaminants from surface soil (distributed excavated material) via infiltration of precipitation and irrigation water;
- Surface soil erosion (i.e., source depletion) does not occur over the 1,000 year-modeling period;
- The groundwater flow regime under the post-remedial conditions is unchanged from the current configuration (e.g. flow direction, aquifer productivity); and

- DCGLs that reflect 30 years of decay (i.e., apply to the year 2041) are appropriate for Sr-90 and Cs-137. Although a 30-year decay period could have been applied to all radionuclides, Sr-90 ad Cs-137 were selected based on expected peak doses at the onset of exposure and the short half lives of these particular radionuclides.

**Other Possible Conceptual Models for Subsurface Soil DCGL Development**

Other possible conceptual models were considered, such as a drilling worker. A drilling worker scenario would evaluate dose to a hypothetical individual installing the cistern, such as from contamination brought to the surface in the form of drill cuttings that could be set aside near the cistern.

A well driller scenario was evaluated in the Decommissioning EIS. The exposure pathways considered included inadvertent ingestion of contaminated soil, inhalation of contaminated dust, and direct exposure to contaminated water in a cuttings pond. The results, shown in Table H-44, indicate that dose to the hypothetical well driller in a representative area – the unremediated north plateau groundwater plume area after 100 years – would be insignificant (less than 1E-08 mrem per year).

Even considering the larger volume of removed contaminated soil in the two meter diameter cistern scenario, the potential dose to the drilling worker would be much smaller than the dose to a hypothetical resident farmer (see Section 5.4.4). Additionally, exposure to the drilling worker from the excavated Lavery till material would only occur in the final stages of the excavation because the majority of the material removed would be clean overlying soil. This factor would further reduce any potential exposure to the person constructing the hypothetical cistern.

**Streambed Sediment Conceptual Model**

Figure 5-9 illustrates the conceptual model for development of streambed sediment DCGLs. Table 5-6 identifies the exposure pathways considered.

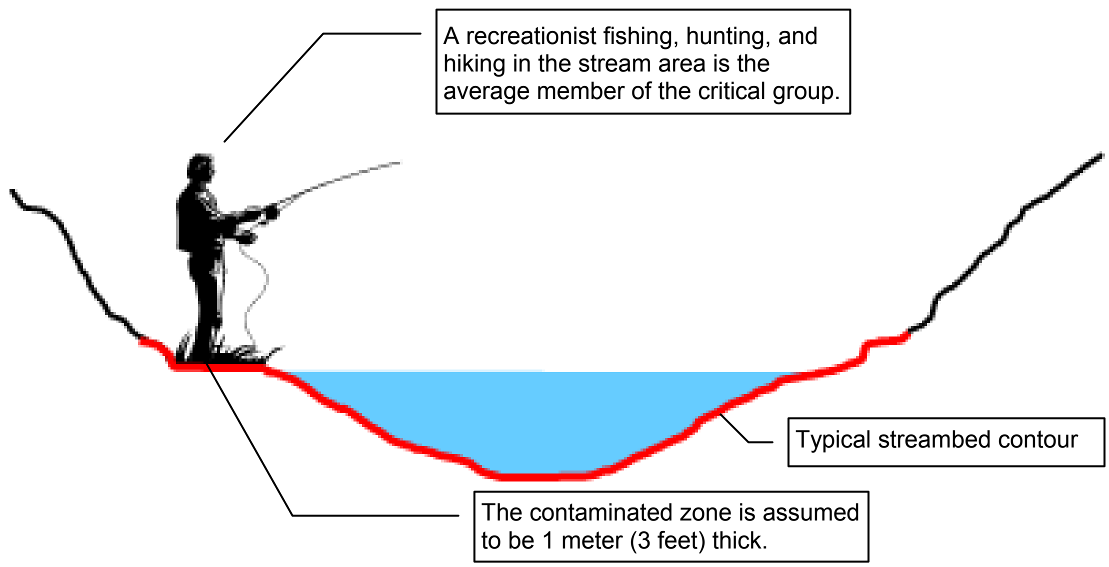



**Figure 5-9. Conceptual Model for Streambed DCGLs Development**

**Table 5-6. Exposure Pathways for Streambed Sediment DCGL Development**

| Exposure Pathways | Active |
|---|---|
| External gamma radiation from contaminated sediment | Yes |
| Inhalation of airborne radioactivity from resuspended contaminated sediment | No(1) |
| Plant ingestion (produce impacted by soil and water sources) | No |
| Meat ingestion (venison impacted by soil and water sources) | Yes |
| Milk ingestion (impacted by soil and water sources) | No |
| Aquatic food ingestion (fish) | Yes |
| Ingestion of drinking water (from groundwater well) | No |
| Ingestion of drinking water (incidental from surface water) | Yes |
| Sediment ingestion (incidental during recreation) | Yes |
| Radon inhalation | No(2) |

NOTES: (1) Sediments adjacent to streambed have significant moisture content that inhibits their resuspension potential and contradicts the consideration of inhalation exposure. Additionally, vegetation along the streambed would likely preclude significant wind scour and subsequent inhalation.

(2) The radon pathway is not considered because radon is primarily naturally occurring and neither radon nor its progeny are among the radionuclides of significant interest in dose modeling.

Key features of this conceptual model include the following:

- A person spending time in the area of the streams for recreation purposes was determined to be the appropriate member of the critical group; the area is not suitable for farming, livestock grazing, or residential use because of the steep stream banks, especially considering further erosion that is likely to occur as discussed previously.
- In this exposure scenario the primary radiation source is considered as the sediment deposited on the stream bank. The ability of sediment to adsorb and absorb radionuclides would be expected to concentrate otherwise dilute species of ions from the water (NRC 1977). The water in the stream provides some shielding and separation from radionuclides in sediments on the stream bottom, thus reducing direct exposure and incidental ingestion pathways from those sources.[8]
- The hypothetical recreationist is assumed to be located on the contaminated stream bank for 104 hours per year, which could involve spending two hours per day, two days per week for 26 weeks a year, reasonable assumptions considering the local climate.

[8] Note that modeling of transport, deposition, and concentrations of radionuclides in the stream itself would require assumptions on potential releases after Phase 1 of the decommissioning, and involve consideration of the Phase 2 end-state, which are not appropriate at this time.

- The contaminated zone of interest is located on the stream bank and is assumed to be three meters (10 feet) wide and 333 meters (1093 feet) long, with a total area of 1000 square meters (approximately ¼ acre).
- Having the contaminated zone on the stream bank takes into account a situation where the stream level might rise significantly then fall again to a lower level.
- The hypothetical recreationist is assumed to eat venison from deer whose flesh is contaminated with radioactivity from contaminated stream banks, such as from grazing on grass, and ingesting stream water.

Consideration was given to both receptor location and stream bank geometry.

Potential doses to a recreationist from impacted stream water would be less significant than potential doses from the stream bank for the following reasons:

- It would be plausible for the hypothetical recreationist to spend more time on the stream bank than immersed in stream water;
- The water would provide radiation shielding for radioactivity in the streambed sediment, which would decrease potential dose from direct radiation;
- While on the stream bank, the external dose from surface water would be negligible compared with the dose from the stream bank source; and
- Neglecting erosion of the stream bank source leads to greater doses than considering erosion of the source from the stream bank to the streambed, where significant shielding from surface water would reduce the dose.

The stream bank geometry was assumed to be represented by a plane source of contamination along the stream bank. Potential doses from alternative source configurations were not included in this evaluation for the following reasons:

- Any dose variation due to a sloped stream bank would likely result in doses similar to level sources due to movement of the receptor and exposure to an equivalent uniform dose (e.g. receptor is assumed to spend time moving throughout the source area and facing all directions for equal amounts of time);
- Although exposure to a source area wider than several meters is unlikely considering the steep terrain, the receptor is assumed to be externally exposed to a circular infinite plane source for conservatism; and
- Because the mass balance model was used for the sediment calculations, the source width parameter is not used in the calculations for water dependent pathways.

All of the input parameters for development of the streambed sediment DCGLs appear in Appendix C. Table 5-7 identifies selected key input parameters.

**Table 5-7. Key Input Parameters for Streambed Sediment DCGL Development(1)**

| Parameter (Units) | Value | Basis |
|---|---|---|
| Area of contaminated zone ($m^2$) | 1.0E+03 | Area on stream bank. |
| Thickness of contaminated zone (m) | 1.0E+00 | Conservative assumption. |
| Fraction of year spent outdoors | 1.2E-02 | 104 hours (out of a total of 8760 hours per year) in area. |
| Cover depth (m) | 0 | Contamination on surface. |
| Contaminated zone erosion rate (m/y) | 0 | Conservative assumption.(2) |
| Well pump intake depth (m below water table) | 0 | Only applicable to farming. |
| Well pumping rate ($m^3$/y) | 0 | Only applicable to farming. |
| Unsaturated zone thickness (m) | 0 | Contamination on stream bank surface. |
| Contaminated zone distribution coefficient for strontium (mL/g) | 1.5E+01 | See Table C-2. |
| Contaminated zone distribution coefficient for cesium (mL/g) | 4.8E+02 | See Table C-2. |
| Contaminated zone distribution coefficient for americium (mL/g) | 4.0E+03 | See Table C-2. |

NOTES: (1) See Appendix C for other input parameters. Metric units are used here because they are normally used in RESRAD.
(2) This assumption is conservative because it results in no erosion of the source.

In development of the conceptual model, consideration was given to protection of environmental and ecological resources, as well as human health. It was determined that no changes to the model or the radioactivity cleanup criteria would be necessary for this purpose.[9]

### 5.2.2 Mathematical Model

As noted previously, RESRAD (Yu, et al. 2001) is used as the mathematical model for DCGL development. Version 6.4 was used to calculate the unit dose factors (in mrem/y per pCi/g) for each of the 18 radionuclides in each of the three exposure scenarios. Unit dose

[9] DOE Order 450.1, *Environmental Protection Program*, requires that DOE Environmental Management facilities such as the WVDP have an environmental management system to ensure protection of the air, water, land, and other natural and cultural resources in compliance with applicable environmental; public health; and resource protection laws, regulations, and DOE requirements. Implementing guidance includes DOE Standard 1153-2002, *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota.* This guidance includes the use of biota concentration guides to evaluate potential adverse ecological effects from exposure to radionuclides.

The WVDP routinely evaluates potential annual doses to aquatic and riparian animals and plants in relation to the biota concentration guides using the RESRAD-BIOTA computer code (DOE 2004) and radionuclide concentrations measured in water and streambed sediment. These evaluations show compliance with the guides (WVES and URS 2008). The environmental monitoring and control program for Phase 1 of the decommissioning described in Section 1.8 would ensure compliance with DOE Order 450.1 during the decommissioning activities.

factors were then scaled in Microsoft Excel to calculate individual radionuclide DCGLs corresponding to 25 mrem per year.

RESRAD was selected as the mathematical model for DCGL development due to the extensive use by DOE and by NRC licensees in evaluating doses from residual radioactivity at decommissioned sites. The RESRAD model considers multiple exposure pathways for direct contact with radioactivity, indirect contact, and food uptake, which are the conditions being evaluated at the WVDP.

RESRAD was used with the post-Phase 1 conceptual models described previously to generate doses for unit radionuclide source concentrations (i.e., dose per pCi/g of source). The resulting doses were then scaled to the limiting acceptable dose (25 mrem in a year) to provide the radionuclide specific DCGLs (see Appendix C). For example, the maximum estimated annual dose from 1 pCi/g of Cs-137 in surface soil was determined to be 1.7 mrem, so the DCGL for 25 mrem per year is 25 divided by 1.7 or 14.8 pCi/g prior to accounting for decay (see Table C-5). The calculated DCGLs were then input into the model as the source concentration to verify that the dose limit of 25 mrem per year was not exceeded.

Among the general considerations for the application of RESRAD to the post-Phase 1 decommissioning conceptual models were:

- Use of the non-dispersion groundwater pathways model for surface soil due to the relatively large source area;
- Use of the mass balance model, instead of the less conservative non-dispersion model, for the subsurface and streambed sediment models due to the relatively small source areas; and
- The conservative assumption of no erosion for soil and sediment sources in the development of DCGLs, so there would be no source depletion from erosion.

RESRAD input parameters were selected from the following sources, generally in the order given based on availability:

- Site-specific values where available, (e.g. groundwater and vadose zone parameters such as the distribution coefficients listed in Table 3-20);
- Semi site-specific literature values, (e.g. physical values based on soil type from NUREG/CR-6697 (Yu, et al. 2000) and behavioral factors based on regional data in the U.S. Environmental Protection Agency's *Exposure Factors Handbook* (EPA 1997);
- Scenario-specific values using conservative industry defaults, (e.g., from the *Exposure Factors Handbook*, the *RESRAD Data Collection Handbook* (Yu, et al. 1993), NUREG/CR-6697 (Yu, et al. 2000), and NUREG/CR-5512, Volume 3 (Beyeler, et al. 1999);
- The most likely values among default RESRAD parameters defined by a distribution, when available, otherwise mean values from NUREG/CR-6697 (Yu, et al. 2000).

### 5.2.3 Summary of Results

Table 5-8 provides the calculated individual radionuclide DCGLs for surface soil, subsurface soil, and streambed sediment which assure that the dose to the average member of the critical group would not exceed 25 mrem per year when considering the dose contribution from each radionuclide individually.

**Table 5-8. DCGLs For 25 mrem Per Year (pCi/g)**

| Nuclide | Surface Soil | | Subsurface Soil | | Streambed Sediment | |
|---|---|---|---|---|---|---|
| | $DCGL_W$ | $DCGL_{EMC}$ (1) | $DCGL_W$ | $DCGL_{EMC}$ (1) | $DCGL_W$ | $DCGL_{EMC}$ (1) |
| Am-241 | 5.4E+01 | 4.4E+03 | 6.4E+03 | 4.6E+04 | 1.6E+04 | 3.7E+05 |
| C-14 | 3.5E+01 | 1.7E+06 | 4.3E+05 | 1.5E+08 | 3.4E+03 | 1.1E+07 |
| Cm-243 | 4.7E+01 | 8.4E+02 | 1.1E+03 | 9.0E+03 | 3.6E+03 | 3.3E+04 |
| Cm-244 | 1.0E+02 | 1.4E+04 | 2.0E+04 | 1.5E+05 | 4.7E+04 | 3.2E+07 |
| Cs-137 (2) | 2.9E+01 | 3.4E+02 | 4.4E+02 | 3.7E+03 | 1.3E+03 | 1.2E+04 |
| I-129 | 6.5E-01 | 2.1E+03 | 4.2E+02 | 4.3E+04 | 3.7E+03 | 9.3E+05 |
| Np-237 | 1.1E-01 | 2.3E+02 | 3.7E+01 | 3.7E+03 | 5.4E+02 | 1.7E+04 |
| Pu-238 | 6.4E+01 | 8.5E+03 | 1.2E+04 | 9.2E+04 | 2.0E+04 | 1.6E+07 |
| Pu-239 | 5.8E+01 | 7.7E+03 | 1.1E+04 | 8.3E+04 | 1.8E+04 | 1.4E+07 |
| Pu-240 | 5.8E+01 | 7.7E+03 | 1.1E+04 | 8.3E+04 | 1.8E+04 | 1.5E+07 |
| Pu-241 | 1.8E+03 | 1.5E+05 | 2.2E+05 | 1.5E+06 | 5.2E+05 | 1.3E+07 |
| Sr-90 (2) | 9.7E+00 | 8.9E+03 | 3.1E+03 | 2.0E+05 | 9.5E+03 | 1.5E+06 |
| Tc-99 | 3.2E+01 | 5.4E+04 | 1.1E+04 | 1.1E+06 | 2.2E+06 | 1.4E+08 |
| U-232 | 6.3E+00 | 6.7E+01 | 1.2E+02 | 1.0E+03 | 2.7E+02 | 2.5E+03 |
| U-233 | 2.2E+01 | 1.6E+04 | 1.7E+03 | 1.6E+05 | 5.8E+04 | 1.6E+06 |
| U-234 | 2.3E+01 | 2.6E+04 | 1.7E+03 | 1.7E+05 | 6.1E+04 | 1.5E+07 |
| U-235 | 1.6E+01 | 6.7E+02 | 9.5E+02 | 7.5E+03 | 2.9E+03 | 2.5E+04 |
| U-238 | 2.4E+01 | 3.3E+03 | 1.8E+03 | 3.7E+04 | 1.3E+04 | 1.3E+05 |

NOTES: (1) $DCGL_{EMC}$ values are for an area 1 $m^2$ in size.
(2) Sr-90 and Cs-137 DCGLs reflect 30 years of decay and apply to the year 2041 and later.

The $DCGL_{EMC}$ values were calculated using each RESRAD model with an area of one square meter for the contaminated zone, in place of the larger contaminated zone area assumed in the base case model. This calculation produced the maximum dose in mrem per year in the peak year for a one square meter contaminated zone, which was used to estimate the $DCGL_{EMC}$ value.

As noted previously, the sum-of-fractions rule would be applied if characterization data indicate that a mixture of radionuclides is present in an area.

### Conclusions About Results

Detailed outputs of the RESRAD simulations are presented in Appendix C. For surface soil, the results show that:

- Am-241 doses are due primarily to ingestion of plants,
- Cs-137 doses are due primarily to external exposure, and
- Sr-90 doses are due primarily to ingestion of plants.

The modeling to develop the subsurface soil DCGLs indicated that:

- Am-241 doses are due primarily to external exposure and ingestion of impacted plants,
- Cs-137 doses are due primarily to external exposure,
- Sr-90 doses are due primarily to ingestion of impacted plants, and
- DCGLs for subsurface soil are greater than those for the surface soil.

The modeling to develop the streambed sediment DCGLs indicated that:

- Am-241 doses are due primarily to incidental ingestion of sediment and to external exposure,
- Cs-137 doses are due primarily to external exposure, as well as ingestion of soil and venison,
- Sr-90 doses are due primarily to ingestion of venison, and
- DCGLs for the sediment source are orders of magnitude greater than those for surface soil.

### Conservatism in Calculations

A number of factors make the calculated DCGLs conservative. For the surface soil DCGLs, these factors include, for example:

- Based on limited available data, the typical thickness of the contaminated zone is likely smaller than the one meter (about 3.3 feet) value used in the analysis.
- Because of the relatively short local growing season, it is likely that crop and forage yields would be less than those assumed for the site.

For the subsurface soil DCGLs, conservative factors include:

- As discussed previously, the diameter of the hypothetical well (cistern) at two meters (about 6.6 feet) is much larger than the diameter of a typical water well (eight inches)[10].

[10] With the larger diameter, much more contaminated soil and residual radioactivity would be brought to the surface where it could cause exposure through various pathways. The difference in volume would vary with the square of the radius; 100 times as much contaminated soil would be brought to the surface in the conceptual model with the two meter diameter well than with a model that assumed a 20 centimeter (eight inch) diameter well. The larger diameter well assumed ensures that the pumping needs of the residential farm would be met, since a smaller diameter well could not do this on some parts of the project premises.

- Use of the mass balance model within RESRAD is conservative in that all radionuclide inventory in leachate reaches the intake well.
- Because of the relatively short local growing season, it is likely that crop/forage yields would be less than those assumed for the site.

For the streambed sediment DCGLs, conservative factors include:

- Based on limited available data, the typical thickness of the contaminated zone is likely smaller than the one meter (about 3.3 feet) value used in the analysis.
- Based on available data, most contamination will be found in the stream beds, not on the banks.
- It is unlikely that the incidental ingestion rate (50 mg/d) for sediment will be exclusively from the contaminated area.
- It is assumed that all fish ingested by the recreationist are impacted by the streambed sediment source; however, it is more likely that a recreationist may ingest fish from other locations as well.
- Similarly, it is unlikely that the venison ingested would be impacted by streambed sediment sources exclusively. It is more likely that exposure would be from both impacted and non-impacted areas.
- Assumptions regarding the availability of an adequate fish population to allow long term fish ingestion may also result in overestimation of doses related to the sediment source, as there are currently no fish in the streams of sufficient quality or quantity for sustained human consumption.

### 5.2.4 Discussion of Sensitivity Analyses and Uncertainty

Table 5-9 summarizes the sensitivity analyses performed for the surface soil DCGLs, which are detailed in Appendix C.

**Table 5-9. Summary of Parameter Sensitivity Analyses – Surface Soil DCGLs**(1)

| Parameter (Base Case) | Run | Change Made | Minimum DCGL Change | | Maximum DCGL Change | |
|---|---|---|---|---|---|---|
| | | | Change | Nuclide(s) | Change | Nuclide(s) |
| Indoor/Outdoor Fraction (0.66/0.25) | 1 | -32% | -23% | U-232 | 0% | I-129 |
| | 2 | 21% | 0% | I-129 U-234 | 30% | U-232 |
| Source Thickness (1 m) | 3 | -50% | 9% | Cs-137 | 82% | Sr-90 |
| | 4 | 200% | -30% | U-235 | -0.1% | Cs-137 |
| Unsaturated Zone Thickness (2 m) | 5 | -50% | -2% | U-238 | 6% | U-235 |
| | 6 | 150% | -4% | U-235 | 1% | U-238 |
| Irrigation/Pump Rate (0.5 m/y/ 5720 $m^3$/y) | 7 | -57% | -1% | U-232 | 52% | I-129 |
| | 8 | 70% | -31% | I-129 | 2% | U-232 |

**Table 5-9. Summary of Parameter Sensitivity Analyses – Surface Soil DCGLs(1)**

| Parameter (Base Case) | Run | Change Made | Minimum DCGL Change | | Maximum DCGL Change | |
|---|---|---|---|---|---|---|
| | | | Change | Nuclide(s) | Change | Nuclide(s) |
| Soil/Water Distribution Coefficients ($K_d$) (Table C-2) | 9 | lower | -67% | Sr-90 | 6% | U-232 |
| | 10 | higher | -4% | U-232 | 1146% | U-234 |
| Hydraulic Conductivity (140 m/y) | 11 | -99% | 0% | Sr-90 | 1873% | I-129 |
| | 12 | 150% | 0% | Cs-137, Sr-90, U-232 | 122% | U-235 |
| Runoff/Evapotrans-poration Coefficient (0.6/0.55) | 13 | -69% | -28% | U-234 | 3% | U-232 |
| | 14 | 64% | -3% | U-232 | 121% | U-234 |
| Depth of Well Intake (5 m) | 15 | -40% | -42% | I-129 | 0.1% | U-232 |
| | 16 | 100% | 0% | Cs-137 | 92% | I-129 |
| Length Parallel to Aquifer Flow (100 m) | 17 | -50% | 0% | Cs-137 | 78% | U-235 |
| | 18 | 100% | -44% | U-235 | 0.1% | U-232 |
| Plant Transfer Factors (RESRAD default) | 19 | -90% | -4% | I-129 | 387% | Sr-90 |
| | 20 | 900% | -90% | Sr-90 | -6% | I-129 |
| Mass Balance Model (non-dispersion model) | 21 | -69% | -81% | U-234 | 0.1% | U-232 |
| Contaminated Layer Area (10,000 m$^2$) | - | Various smaller areas | - | - | - | See note (1) |

NOTES: (1) Information from the $DCGL_{EMC}$ calculations was used for evaluation of the sensitivity of the contaminated layer area. DCGLs generally increased with smaller areas. Results presented here are for radionuclides considered likely to contribute significantly to the overall surface soil dose based on available characterization data.

### Discussion of Surface Soil Results

The uncertainty results for the surface soil source model been evaluated considering those radionuclides that are the primary dose drivers, i.e., those that are likely to contribute significantly to predicted dose based on available characterization data. The radionuclides are Sr-90 (due to water independent plant uptake), I-129 (due to water dependent pathways), Cs-137 (external radiation dose), and most uranium radionuclides (water dependent pathways).

The sensitivity analysis of the surface soil model, for these radionuclides, indicates the following:

- A lower indoor exposure fraction results in the largest DCGL decrease for U-232 and no change for I-129. Similarly, a higher indoor exposure fraction results in the largest increase for U-232 and no change for I-129 and U-234. However, it is unlikely that the indoor fraction is too low based on the local climate. The U-232 doses are mainly due to external exposure, which accounts for the relative sensitivity to this parameter.
- Decreasing the source thickness increased the DCGL for all radionuclides and increasing the source thickness resulted in the most significant DCGL decrease for U-235. The sensitivity to this parameter is due to increased/decreased dose from the water ingestion and plant pathways (both water dependent and independent).
- Decreasing the unsaturated zone thickness resulted in an increased DCGL for U-235 and a decrease for U-238. Similarly, increasing the unsaturated zone thickness decreased the U-235 DCGL and increased the U-238 DCGL. Sensitivity to this parameter is mainly due to increased/decreased travel time of contaminants to the saturated zone, resulting in water dependent doses occurring earlier/later with respect to doses from water independent pathways.
- Reducing the irrigation/well pump rate increased the DCGL for I-129 most significantly. Similarly, increasing the pump rate decreased the DCGL for I-129. This is because reducing the pumping rate results in a lower dilution factor, and increasing the pumping rate results in more radionuclide inventory available for exposure.
- The most significant effects of varying the $K_d$ values were observed for Sr-90 and U-234.
- Decreasing the hydraulic conductivity significantly increased the DCGL for I-129 due to increasing the travel time to the well. Increasing the hydraulic conductivity significantly increased the DCGL for U-235 because dilution is greater.
- Variations in the runoff/evapotranspiration coefficients had the greatest effect on U-234 and the least impact on U-232. Radionuclides that are most sensitive to this parameter have doses mainly due to water dependent pathways.
- Decreasing the well intake depth most significantly decreased the DCGL for I-129, while increasing this parameter results in significantly increased the DCGL for I-129, due to increased/decreased dilution in the well water.

- Changes to the parameter for length of contamination parallel to the aquifer flow had the most significant effect on the U-235 DCGL, due to increased/decreased dilution in the aquifer.
- Decreasing/increasing the plant transfer factors significantly increased/decreased the DCGL for Sr-90, as dose is mainly due to ingestion via plant uptake from soil.
- Use of the mass balance groundwater model significantly decreases the DCGL for U-234 but had no effect on U-232. Radionuclides most sensitive to this parameter have doses mainly due to water dependent pathways.

Table 5-10 summarizes the sensitivity analyses performed for the subsurface soil DCGLs, which are detailed in Appendix C.

**Table 5-10. Summary of Parameter Sensitivity Analyses – Subsurface Soil DCGLs**[(1)]

| Parameter (Base Case) | Run | Change Made | Minimum DCGL Change | | Maximum DCGL Change | |
|---|---|---|---|---|---|---|
| | | | Change | Nuclide(s) | Change | Nuclide(s) |
| Indoor/Outdoor Fraction (0.66/0.26) | 1 | -32% | -25% | Cs-137 | 0.1% | U-234 |
| | 2 | 21% | -1% | U-238 | 35% | U-232 |
| Source Thickness (1m) | 3 | -67% | 10% | U-238 | 193% | Sr-90 |
| | 4 | 233% | -66% | Sr-90 | -1% | Cs-137 |
| Unsaturated Zone Thickness (2 m) | 5 | -50% | -1% | U-238 | 0% | Cs-137, Sr-90, U-232, U-235 |
| | 6 | 150% | 0% | Cs-137 Sr-90 U-232 U-235 | 1% | U-238 |
| Irrigation/Pump Rate (0.5 m/y/ 5720 $m^3$/y) | 7 | -57% | -36% | I-129 | 0% | Cs-137 |
| | 8 | 70% | 0% | Cs-137 | 159% | U-238 |
| Soil/Water Distribution Coefficients ($K_d$) (Table C-2) | 9 | lower | -85% | U-238 | 9% | U-232 |
| | 10 | higher | -27% | U-232 | 3144% | U-234 |
| Hydraulic Conductivity (140 m/y) | 11 | -99% | -1% | U-238 | 3% | I-129 |
| | 12 | 150% | 0% | Cs-137 I-129 Sr-90 U-232 U-233 U-234 U-235 U-238 | 0% | Cs-137, I-129, Sr-90, U-232, U-233, U-234, U-235, U-238 |
| Runoff/Evapotranspiration Coefficient (0.6/0.55) | 13 | -69% | -38% | U-234 | 16% | U-232 |
| | 14 | 64% | -19% | U-232 | 188% | U-234 |

**Table 5-10. Summary of Parameter Sensitivity Analyses – Subsurface Soil DCGLs(1)**

| Parameter (Base Case) | Run | Change Made | Minimum DCGL Change | | Maximum DCGL Change | |
|---|---|---|---|---|---|---|
| | | | Change | Nuclide(s) | Change | Nuclide(s) |
| Plant Transfer Factors (RESRAD defaults) | 15 | -90% | -0.4% | U-238 | 574% | Sr-90 |
| | 16 | 900% | -89% | Sr-90 | -1% | U-234 |
| Contaminated Layer Area (100 $m^2$) | - | Various smaller areas | - | - | - | See note (1). |

NOTES: (1) Information from the $DCGL_{EMC}$ calculations was used for evaluation of the sensitivity of the contaminated layer area. DCGLs generally increased with smaller areas. Results presented here are for radionuclides considered likely to contribute significantly to the overall subsurface soil dose based on available characterization data.

### Discussion of Subsurface Soil Results

The uncertainty results for the subsurface soil source models have been evaluated considering those radionuclides that are the primary dose drivers, i.e., those that are likely to contribute significantly to predicted dose based on available characterization data (see Table 5-1). The radionuclides are Sr-90 (due to water independent plant uptake), I-129 (due to water dependent pathways), Cs-137 (external radiation dose), and uranium radionuclides (water dependent pathways).

The sensitivity analysis of the subsurface soil model for these radionuclides indicates the following:

- A lower indoor exposure fraction results in a DCGL decrease for Cs-137 and no change for U-234. A higher indoor exposure results in a significant increased DCGL for U-232. However, it is unlikely that the indoor fraction is too low based on the local climate. Doses for these isotopes are mainly due to external exposure, which accounts for the relative sensitivity to this parameter.
- The source thickness parameter sensitivity was most significant for Sr-90 The sensitivity to this parameter is due to increased/decreased dose from the water ingestion and plant pathways (both water dependent and independent).
- Decreasing or increasing the unsaturated zone thickness resulted in little change to the DCGLs.
- The I-129 and U-238 DCGLs were sensitive to changes in the irrigation/well pump rate but the Cs-137 DCGL was not. This effect is because reducing the pumping rate results in a lower dilution factor, and increasing the pumping rate results in more dilution for water dependent pathways.
- The most significant effects of varying the $K_d$ values were observed for U-232, U-234, and U-238.
- Decreasing or increasing the hydraulic conductivity resulted in no change to the DCGLs due to use of the mass balance model.

- The U-232 and U-234 DCGLs are sensitive to changes in the runoff/ evapotranspiration coefficient. Radionuclides that are most sensitive to this parameter have doses mainly due to water dependent pathways.
- The plant transfer factor is most sensitive for Sr-90, as the dose is mainly due to ingestion via plant uptake.

Table 5-11 summarizes the sensitivity analyses performed for the streambed sediment DCGLs, which are detailed in Appendix C:

**Table 5-11. Summary of Parameter Sensitivity Analyses – Streambed Sediment DCGLs(1)**

| Parameter (Base Case) | Run | Change Made | Minimum DCGL Change | | Maximum DCGL Change | |
|---|---|---|---|---|---|---|
| | | | Change | Nuclide(s) | Change | Nuclide(s) |
| Indoor/Outdoor Fraction (0.66/0.25) | 1 | -50% | 3% | Sr-90 | 86% | Cs-137 |
| | 2 | 100% | -48% | Cs-137 | -5% | Sr-90 |
| Source Thickness (1 m) | 3 | -50% | 1% | Cs-137 | 29% | Sr-90 |
| | 4 | 200% | -0.2% | Sr-90 | 0% | Cs-137 |
| Unsaturated Zone Thickness (2 m) | 5 | 0 m to 1m | 0.3% | Cs-137 | 8% | Sr-90 |
| | 6 | 0 m to 3 m | 0.3% | Cs-137 | 8% | Sr-90 |
| Soil/Water Distribution Coefficients ($K_d$) (Table C-2) | 7 | lower | 0.5% | Cs-137 | 12% | Sr-90 |
| | 8 | higher | 0.3% | Cs-137 | 7% | Sr-90 |
| Runoff/Evaporation Coefficient (0.6/0.55) | 9 | -54% | 0% | Cs-137 | 0.4% | Sr-90 |
| | 10 | 78% | -0.3% | Sr-90 | 0% | Cs-137 |
| Plant Transfer Factors (RESRAD defaults) | 11 | -90% | 1% | Cs-137 | 82% | Sr-90 |
| | 12 | 900% | -82% | Sr-90 | -9% | Cs-137 |
| Fish Transfer Factors (RESRAD defaults) | 13 | -90% | 0.3% | Cs-137 | 7% | Sr-90 |
| | 14 | 900% | -39% | Sr-90 | -3% | Cs-137 |
| Contaminated Layer Area (1000 $m^2$) | - | Various smaller areas | - | - | - | See note (1). |

NOTES: (1) Information from the $DCGL_{EMC}$ calculations was used for evaluation of the sensitivity of the contaminated layer area. DCGLs generally increased with smaller areas. Results presented here are for radionuclides considered likely to contribute significantly to the overall sediment dose based on available characterization data.

**Discussion of Streambed Sediment Results**

The streambed sediment model sensitivity simulations have been evaluated considering those radionuclides that are likely to significantly contribute to the overall doses in this media, which are Sr-90 (venison ingestion) and Cs-137 (external radiation dose).

The sensitivity analysis for the sediment model, for these radionuclides, indicates:

- The DCGLs for Sr-90 and Cs-137 are inversely related to changes in outdoor fraction, with Cs-137 being the most sensitive. Radionuclides with primary doses from water independent pathways are more sensitive to changes in this parameter.
- Decreasing the source thickness results in higher DCGLs for Sr-90 and Cs-137. While increasing the source thickness has little effect on these radionuclides. Sr-90 is most sensitive to this parameter.
- Increasing the unsaturated zone thickness increases DCGLs for Sr-90 but had no effect on Cs-137. Radionuclides with primary doses from water dependent pathways are more sensitive to changes in this parameter.
- Varying the $K_d$ values had no effect on the Cs-137 DCGLs, but increased the Sr-90 DCGLs due to doses from water dependent pathways.
- Varying the runoff/evapotranspiration coefficient had little effect on Cs-137 or Sr-90 DCGLs. Radionuclides most sensitive to this parameter have doses mainly due to water dependent pathways.
- Decreasing both plant and fish transfer factors resulted in increased DCGLs for Sr-90, and increasing these parameters resulted in decreased DCGLs for both Cs-137 and Sr-90.

**Other Uncertainties**

The RESRAD model does not account for the fate and transport of eroded particles due to surface soil source erosion/overland transport, and the rate of erosion input for RESRAD is only used to deplete the source. The assumption of no sediment source erosion is considered an appropriate simplification since it provides a conservative estimate of dose based on no source depletion via erosion. Additionally, while overland erosion via runoff is not considered, neither is the receiving water body diluted by the runoff.

The assumption of no change to groundwater conditions in terms of flow direction and aquifer productivity is a source of potential uncertainty. However, DCGLs based on this assumption can be further refined if site specific information indicates different conditions are likely.

**Leaching of Residual Subsurface Contamination to Groundwater**

The evaluation of DCGL radioactivity concentrations in the Lavery till (that is, at the bottom of the WMA 1 and WMA 2 excavations) as a continuing source to groundwater could not be modeled using RESRAD, because the code does not provide for a site configuration with a source below the water table. Pore water concentrations estimated from the soil partition coefficients indicate that even assuming minimal dilution, the resulting well concentration would be low compared with the contribution from well cuttings leaching from the surface (see Appendix C). The uncertainty in neglecting this contribution to the overall dose is considered to be acceptable when considering the large percentage of the dose from pathways associated with subsurface soil cuttings spread on the surface compared to the potential dose from leaching of residual radioactivity at the bottom of the WMA 1 and WMA 2 excavations.

The following conditions suggest that the dose associated with subsurface soil cuttings as a surface source does not warrant consideration in the overall combined dose assessment:

- Even with conservative assumptions of a large cistern diameter and well depth, combined with a small thickness over which the cuttings are spread, the result is a source area of approximately 1,000 square feet (100 square meters). When this source area is used in conjunction with the required area for a resident farmer of 100,000 square feet (10,000 square meters), the result is a large DCGL for subsurface soil when compared with surface soil DCGLs (except in the case of Cs-137).
- Dilution of contaminated well cuttings with overlying clean fill results in further reduction of overall dose from subsurface sources relative to surface sources.
- Doses from potential surface soil sources are orders of magnitude greater than those from subsurface sources based on the resident farmer scenario.

**Changes to Base-Case Models Based on Sensitivity Analysis Results**

Development of the conceptual model for surface soil DCGLs was an iterative process that used conservative assumptions for model parameters and took into account the results of early model runs and the related input parameter sensitivity analyses.

The initial model runs produced inordinately low DCGLs for uranium radionuclides in surface soil. The calculated $DCGL_W$ for U-238, for example, was 1.0 pCi/g, slightly above measured background concentrations in surface soil shown in Table 4-11 of this plan.

The next iteration involved changes to radionuclide distribution coefficients. Evaluation of the basis for the original distribution coefficients and sensitivity analysis results led to the conclusion that some distribution coefficients used were inappropriate. These distribution coefficients were changed. The resulting distribution coefficients are based either on site-specific data for the sand and gravel layer or, where site-specific data are not available, values for sand from Sheppard and Thibault 1990, as shown in Table C-2.

These model changes produced higher $DCGL_W$ values for uranium radionuclides, e.g., 4.8 pCi/g for U-238. However, these values were still low compared to uranium DCGLs for unrestricted release developed at other sites. Further evaluation showed that the main reason for the low uranium DCGLs was the conservative use of the RESRAD mass balance model. After considering the results of the sensitivity analysis that evaluated use of the non-dispersion model, and RESRAD Manual guidance[11], it was determined to be more appropriate to use the non-dispersion model in the surface soil analysis and this was done.

No other conceptual model changes were considered to be necessary given the approach of selecting input parameters that are generally conservative and taking into account the built-in modeling conservatism from selecting peak doses from all years and neglecting the decay of long-lived radionuclides. For the subsurface soil DCGL model, because of the limited amount of material excavated and distributed on the surface, the contaminated layer thickness at the ground surface was not increased (this provides a larger area over which to spread subsurface cuttings).

**Overall Conclusion**

The DCGLs developed for Phase 1 of the proposed decommissioning as shown in Table 5-8 are protective of human health. Evaluation of the dose modeling results indicates that:

- Primary contributions to dose associated with surface soil sources are due to external exposure to Cs-137 in surface soil, and ingestion of Sr-90 in plants. Surface soil source results indicate that Cs-137 dose is most sensitive to changes in the indoor/outdoor fraction and plant transfer factors, while Sr-90 is sensitive to changes in the contaminated zone thickness, plant transfer factors, and the use of the mass balance groundwater model.
- Primary contributions to dose associated with subsurface sources are due to external exposure to Cs-137 in excavated material, and ingestion of Sr-90 in plants. Subsurface soil source results indicate that Cs-137 is most sensitive to changes in indoor/outdoor fraction and source thickness. Sr-90 is most sensitive to source thickness and plant transfer factors.
- Primary contributions to dose associated with sediment sources are due to external exposure to Cs-137 in sediment, and ingestion of Sr-90 in venison. Sediment source results indicate that Cs-137 dose is most sensitive to the indoor/outdoor fraction, while Sr-90 is sensitive to plant transfer factors.

The DCGLs developed as described in this section were based on exposure to a single radionuclide in a specific source media (e.g., Sr-90 in sediment). The next section discusses refinement of the DCGLs to account for exposure to multiple radionuclides and sources.

## 5.3 Limited Site-Wide Dose Assessment

This section describes the limited integrated dose assessment performed to ensure that criteria used in Phase 1 remediation activities would not limit options for Phase 1 of the proposed decommissioning.

[11] The RESRAD Manual (Yu, et al. 2001) notes in Appendix E that:"The user has the option of selecting which [groundwater] model to use. Usually, the MB [mass balance] model is used for smaller contaminated areas (e.g., 1,000 $m^2$ or less) and the ND [non-dispersion] model is used for larger areas."

### 5.3.1 Basis for this Assessment

Section 5.1.3 explains why such a dose assessment is appropriate, considering the Phase 1 and Phase 2 sources illustrated in Figure 5-4. Section 5.1.3 also explains that the appropriate dose assessment involves a hypothetical individual engaged in farming at some time in the future on one part of the remediated project premises who also spends time fishing and hiking at Erdman Brook and Franks Creek.

This scenario would involve an individual being exposed to two different remediated source areas and being a member of the two different critical groups. As described in Section 5.2, the exposure group for the resident farmer scenario used for development of DCGLs for surface and subsurface soil is significantly different from the exposure group for the development of the streambed sediment DCGLs, which involves a hypothetical individual spending a relatively small fraction of his or her time hiking, fishing, and hunting in the areas of Erdman Brook and Franks Creek.

In both of these cases, it was assumed that the hypothetical individual (the average member of the critical group) would be exposed only to the residual radioactivity of interest. That is, the resident farmer would not be exposed to residual radioactivity in the areas of the streams and the recreationist would not be exposed to residual radioactivity in surface soil or subsurface soil.

### 5.3.2 Assessment Approach

The approach used involves partitioning doses between two critical groups and two areas of interest: (1) the resident farmer who lives in an area of the project premises where surface soil or subsurface soil has been remediated to the respective DCGLs and (2) the person who spends time in the areas of the streams hiking, fishing, and hunting (the recreationist). This approach is analogous to addressing multiple radionuclides in contaminated media of interest using the sum-of-fractions approach or unity rule (NRC 2006).

Consideration of potential risks related to the different areas led assigning 90 percent of the total dose limit of 25 mrem per year to the resident farmer activities and 10 percent to the recreational activities. This arrangement involves assigning an acceptable dose of 22.5 mrem per year to resident farmer activities and 2.5 mrem per year to recreation in the area of the streams, values which total 25 mrem per year.[12] The assessment was then performed using the base case analysis results for the resident farmer and the recreationist at Erdman Brook and Franks Creek.

Two separate assessments were performed with the resident farmer located in: (1) the area of the remediated WMA 1 subsurface soil excavation, and (2) the resident farmer

[12] This 0.90/0.10 split is based on judgment related to relative risk. Consideration was given to using a split based on the relative time the hypothetical farmer would spend in the area of the farm compared to the area of the streams. However, because the assumed time in the area of the streams is relatively small at 104 hours per year, such as spilt could result in an allowable annual dose of 24.7 mrem for resident farmer activities and 0.3 mrem for recreation at the streams. This split would have a minimal impact on the soil DCGLs while driving the streambed sediment DCGLs to unrealistically low levels.

located in an area where surface soil was assumed to have been remediated. Details appear in Appendix C.

### 5.3.3 Results of the Assessments

Table 5-12 provides the assessment results for the WMA 1 subsurface soil case and Table 5-13 provides the results for the surface soil case. The streambed sediment $DCGL_W$ values are the same in both cases because the apportioned dose limit of 2.5 mrem per year is the same.

**Table 5-12. Limited Site-Wide Dose Assessment 1 Results (DCGLs in pCi/g)**

| Nuclide | Subsurface Soil $DCGL_W$ Values | | Streambed Sediment $DCGL_W$ Values | |
|---|---|---|---|---|
| | Base Case(1) | Assessment(2) | Base Case(1) | Assessment(2) |
| Am-241 | 6.4E+03 | 5.8E+03 | 1.6E+04 | 1.6E+03 |
| C-14 | 4.3E+05 | 3.8E+05 | 3.4E+03 | 3.4E+02 |
| Cm-243 | 1.1E+03 | 1.0E+03 | 3.6E+03 | 3.6E+02 |
| Cm-244 | 2.0E+04 | 1.8E+04 | 4.7E+04 | 4.7E+03 |
| Cs-137(3) | 4.4E+02 | 3.9E+02 | 1.3E+03 | 1.3E+02 |
| I-129 | 4.2E+02 | 3.8E+02 | 3.7E+03 | 3.7E+02 |
| Np-237 | 3.7E+01 | 3.3E+01 | 5.4E+02 | 5.4E+01 |
| Pu-238 | 1.2E+04 | 1.1E+04 | 2.0E+04 | 2.0E+03 |
| Pu-239 | 1.1E+04 | 9.9E+03 | 1.8E+04 | 1.8E+03 |
| Pu-240 | 1.1E+04 | 9.9E+03 | 1.8E+04 | 1.8E+03 |
| Pu-241 | 2.2E+05 | 2.0E+05 | 5.2E+05 | 5.2E+04 |
| Sr-90(3) | 3.1E+03 | 2.8E+03 | 9.5E+03 | 9.5E+02 |
| Tc-99 | 1.1E+04 | 9.9E+03 | 2.2E+06 | 2.2E+05 |
| U-232 | 1.2E+02 | 1.1E+02 | 2.7E+02 | 2.7E+01 |
| U-233 | 1.7E+03 | 1.5E+03 | 5.8E+04 | 5.8E+03 |
| U-234 | 1.7E+03 | 1.5E+03 | 6.1E+04 | 6.1E+03 |
| U-235 | 9.5E+02 | 8.6E+02 | 2.9E+03 | 2.9E+02 |
| U-238 | 1.8E+03 | 1.6E+03 | 1.3E+04 | 1.3E+03 |

NOTE: (1) The base case values from Table 5-8.
(2) The results for the analysis of the combined resident farmed located in the area of remediated surface soil and the recreationist in the area of the streams.
(3) These DCGLs apply in the year 2041 and later.

As can be seen from Table 5-13, the dose partitioning approach reduced the $DCGL_W$ values for surface soil by 10 percent and reduced the $DCGL_W$ values for streambed sediment by an order of magnitude.

**Table 5-13. Limited Site-Wide Dose Assessment 2 Results (DCGLs in pCi/g)**

| Nuclide | Surface Soil $DCGL_W$ Values | | Streambed Sediment $DCGL_W$ Values | |
|---|---|---|---|---|
| | Base Case(1) | Assessment(2) | Base Case(1) | Assessment(2) |
| Am-241 | 5.4E+01 | 4.9E+01 | 1.6E+04 | 1.6E+03 |
| C-14 | 3.5E+01 | 3.1E+01 | 3.4E+03 | 3.4E+02 |
| Cm-243 | 4.7E+01 | 4.2E+01 | 3.6E+03 | 3.6E+02 |
| Cm-244 | 1.0E+02 | 9.4E+01 | 4.7E+04 | 4.7E+03 |
| Cs-137(3) | 2.9E+01 | 2.7E+01 | 1.3E+03 | 1.3E+02 |
| I-129 | 6.5E-01 | 5.8E-01 | 3.7E+03 | 3.7E+02 |
| Np-237 | 1.1E-01 | 9.6E-02 | 5.4E+02 | 5.4E+01 |
| Pu-238 | 6.4E+01 | 5.8E+01 | 2.0E+04 | 2.0E+03 |
| Pu-239 | 5.8E+01 | 5.2E+01 | 1.8E+04 | 1.8E+03 |
| Pu-240 | 5.8E+01 | 5.2E+01 | 1.8E+04 | 1.8E+03 |
| Pu-241 | 1.8E+03 | 1.6E+03 | 5.2E+05 | 5.2E+04 |
| Sr-90(3) | 9.7E+00 | 8.7E+00 | 9.5E+03 | 9.5E+02 |
| Tc-99 | 3.2E+01 | 2.9E+01 | 2.2E+06 | 2.2E+05 |
| U-232 | 6.3E+00 | 5.6E+00 | 2.7E+02 | 2.7E+01 |
| U-233 | 2.2E+01 | 2.0E+01 | 5.8E+04 | 5.8E+03 |
| U-234 | 2.3E+01 | 2.1E+01 | 6.1E+04 | 6.1E+03 |
| U-235 | 1.6E+01 | 1.4E+01 | 2.9E+03 | 2.9E+02 |
| U-238 | 2.4E+01 | 2.2E+01 | 1.3E+04 | 1.3E+03 |

NOTE: (1) The base case values from Table 5-8.
(2) The results for the analysis of the combined resident farmed located in the area of remediated surface soil and the recreationist in the area of the streams.
(3) These DCGLs apply in the year 2041 and later.

## 5.4 Cleanup Goals and Additional Analyses

This section (1) identifies the cleanup goals to be used in remediation of surface soil, subsurface soil, and streambed sediment and the basis for these cleanup goals; (2) describes how the DCGLs and the cleanup goals would be later refined; (3) discusses use of surrogate radionuclides; and (4) identifies plans for the dose assessment of the remediated WMA 1 and WMA 2 areas.

### 5.4.1 Cleanup Goals

As explained in Section 5.1.6, the dose modeling process includes establishing cleanup goals below the DCGLs developed to meet the 25 mrem per year unrestricted dose limit that are to be used to guide remediation efforts, considering the results of the analysis of the combined source area exposure scenario described in Section 5.3 and the ALARA analysis described in Section 6.

**Combined Source Area Analysis**

As indicated in Section 5.3, analysis of the limiting scenario for dose integration – a resident farmer living on the remediated project premises who spends time in the vicinity of Erdman Brook and Franks Creek hiking, fishing, and hunting – produced lower $DCGL_W$ values for both critical groups, with the reduction for the recreationist in the area of the streams being a much greater percentage.

**ALARA Analysis**

Section 6 describes the process used to evaluate whether remediation of surface soil, subsurface soil, and streambed sediment below DCGLs based on 25 mrem/y would be cost-effective, following the standard NRC methodology for ALARA analyses. Section 6 provides the results of a preliminary analysis and provides for a final ALARA analysis to be performed during the Phase 1 proposed decommissioning work.

The preliminary ALARA analysis suggests that the costs of removing slightly contaminated soil or sediment at concentrations below the DCGLs for 25 mrem per year would outweigh the benefits. That is, areas where surface soil, subsurface soil, and sediment are remediated to radioactivity concentrations at the DCGLs satisfy the ALARA criteria. The evaluation process balances the cost of offsite disposal of additional radioactively contaminated soil (cost of $6.76 per cubic foot) and the benefits of reduced dose (benefit of $2000 per person-rem as set forth in NRC guidance).

The final ALARA analysis that would be performed during the Phase 1 proposed decommissioning activities would make use of updated information, such as actual rather than predicted waste disposal costs. However, the results would likely be similar to the preliminary analysis.

Section 6 explains that the methods to be used in remediation of contaminated soil and sediment, which involve excavation of the material in bulk quantities, would generally remove more material than necessary to meet the DCGLs. As noted in Section 6, NRC recognizes that soil excavation is a coarse removal process that is likely to remove large fractions of the remaining radioactivity (NRC 1997). The contaminated soil and sediment removal method is therefore expected to produce residual radioactivity concentrations well below the DCGLs.

**Cleanup Goals**

Demonstration that the proposed decommissioning activities have achieved the desired dose-based criteria is through a process described in the *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)* (NRC 2000). Samples of the post-decommissioning media are analyzed for the individual radionuclides of interest (or for a surrogate radionuclide in a mixture[13]), and the *average* concentration is compared to the DCGL using various statistical tests. Because the average concentration is compared to

[13] Section 4.3.2 of the MARSSIM (NRC 2000) describes how for sites with multiple radionuclides it may be practical to measure just one of the contaminants and still demonstrate compliance with cleanup criteria for all of the contaminants through the use of surrogate measurements. Section 9 of this plan discusses the use of surrogate radionuclides in Phase 1 of the decommissioning.

the DCGL, and due to the statistical fluctuations inherent in measuring low concentrations of radioactivity, it is likely that some post-remediation samples would exceed the DCGL. It is not necessary that all samples be below the DCGL, but to increase success in the statistical evaluation, the planned post-remediation average (in-process or cleanup goal) should be somewhat below the DCGL. How far below the DCGL is appropriate depends on the variation of the post-remediation concentration across the area and on the inherent costs in responding to a false positive decision (concluding that remediation was successful but finding that analysis of samples from the area fails the statistical evaluation).

For surface soils and sediments in the WVDP Phase 1 areas, the field cleanup goal need not be too far below the DCGL, if at all. As discussed previously, bulk excavation would generally remove more material than necessary to meet the DCGL, so it is likely that the post-remediation average concentration would be below whatever in-process goal is chosen. And the costs for additional remediation of a surface soil or sediment site, while extra, are not unusually high.

However, for subsurface soils a field cleanup goal should be well below the DCGL because of the large costs to be incurred if additional remediation were necessary to an area that failed the statistical testing. Re-excavating to depth with shoring, engineering controls, and management or disposal of extensive overburden would be expensive compared to excavating some additional material in the original remediation.

Consideration of such factors led to DOE establishing in this plan the cleanup goals shown in Table 5-14.

**Table 5-14. Cleanup Goals to be Used in Remediation in pCi/g(1)**

| Nuclide | Surface Soil(2) | | Subsurface Soil(3) | | Streambed Sediment(2) | |
|---|---|---|---|---|---|---|
| | $CG_w$ | $CG_{EMC}$ | $CG_w$ | $CG_{EMC}$ | $CG_w$ | $CG_{EMC}$ |
| Am-241 | 4.9E+01 | 4.0E+03 | 2.9E+03 | 2.1E+04 | 1.6E+03 | 3.7E+04 |
| C-14 | 3.1E+01 | 1.5E+06 | 1.9E+05 | 6.6E+07 | 3.4E+02 | 1.1E+06 |
| Cm-243 | 4.2E+01 | 7.6E+02 | 5.1E+02 | 4.0E+03 | 3.6E+02 | 3.3E+03 |
| Cm-244 | 9.4E+01 | 1.2E+04 | 8.8E+03 | 6.6E+04 | 4.7E+03 | 3.2E+06 |
| Cs-137(4) | 2.7E+01 | 3.0E+02 | 2.0E+02 | 1.7E+03 | 1.3E+02 | 1.2E+03 |
| I-129 | 5.8E-01 | 1.9E+03 | 1.9E+02 | 1.9E+04 | 3.7E+02 | 9.3E+04 |
| Np-237 | 9.6E-02 | 2.1E+02 | 1.7E+01 | 1.7E+03 | 5.4E+01 | 1.7E+03 |
| Pu-238 | 5.8E+01 | 7.7E+03 | 5.5E+03 | 4.1E+04 | 2.0E+03 | 1.6E+06 |
| Pu-239 | 5.2E+01 | 6.9E+03 | 5.0E+03 | 3.8E+04 | 1.8E+03 | 1.4E+06 |
| Pu-240 | 5.2E+01 | 7.0E+03 | 5.0E+03 | 3.8E+04 | 1.8E+03 | 1.5E+06 |
| Pu-241 | 1.6E+03 | 1.3E+05 | 9.8E+04 | 7.0E+05 | 5.2E+04 | 1.3E+06 |
| Sr-90(4) | 8.7E+00 | 8.0E+03 | 1.4E+03 | 9.1E+04 | 9.5E+02 | 1.5E+05 |
| Tc-99 | 2.9E+01 | 4.9E+04 | 5.0E+03 | 4.9E+05 | 2.2E+05 | 1.4E+07 |
| U-232 | 5.6E+00 | 6.0E+01 | 5.3E+01 | 4.7E+02 | 2.7E+01 | 2.5E+02 |

**Table 5-14. Cleanup Goals to be Used in Remediation in pCi/g(1)**

| Nuclide | Surface Soil(2) | | Subsurface Soil(3) | | Streambed Sediment(2) | |
|---|---|---|---|---|---|---|
| | $CG_w$ | $CG_{EMC}$ | $CG_w$ | $CG_{EMC}$ | $CG_w$ | $CG_{EMC}$ |
| U-233 | 2.0E+01 | 1.4E+04 | 7.5E+02 | 7.2E+04 | 5.8E+03 | 1.6E+05 |
| U-234 | 2.1E+01 | 2.3E+04 | 7.7E+02 | 7.9E+04 | 6.1E+03 | 1.5E+06 |
| U-235 | 1.4E+01 | 6.1E+02 | 4.3E+02 | 3.4E+03 | 2.9E+02 | 2.5E+03 |
| U-238 | 2.2E+01 | 3.0E+03 | 8.2E+02 | 1.7E+04 | 1.3E+03 | 1.3E+04 |

NOTE: (1) These cleanup goals (CGs) are to be used as the criteria for the remediation activities described in Section 7 of this plan.

(2) The $CG_W$ values for surface soil and streambed sediment are the same as the limited dose assessment DCGL values in Table 5-11. The $CG_{EMC}$ values were producing by scaling the values provided in Table 5-8 and apply to 1 $m^2$ areas of elevated contamination.

(3) These $CG_W$ values and $CG_{EMC}$ values are the DCGL values in Table 5-8 reduced by a factor of 0.50 as discussed below.

(4) These cleanup goals apply in the year 2041 and later.

The basis for these cleanup goals is as follows. Compliance with the cleanup goals used for remediation when mixtures of radionuclides are present would be determined by use of the sum-of-fractions approach.

**Basis for Cleanup Goals for Surface Soil**

The surface soil $CG_W$ values are the values in the Surface Soil $DCGL_W$ Assessment column of Table 5-13. DOE considers these goals to be conservative and appropriate to provide assurance that any remediation of surface soil and sediment in drainage ditches on the project premises that may be accomplished during Phase 1 of the proposed decommissioning would support releasing the remediated areas under the criteria of 10 CFR 20.1402, should the licensee eventually determine that approach to be appropriate for Phase 2 of the decommissioning.[14]

**Basis for Cleanup Goals for Subsurface Soil**

DOE has established the subsurface soil cleanup goals at 50 percent of subsurface soil DCGLs calculated in the limited site-wide dose assessments for 22.5 mrem per year (Table 5-12). The cleanup goals for subsurface soil would therefore equate to 11.25 mrem per year. DOE is taking this approach to provide additional assurance that remediation of the WMA 1 and WMA 2 excavated areas would support all potential options for Phase 2 of the proposed decommissioning.

**Basis for Cleanup Goals for Streambed Sediment**

DOE has used the $DCGL_W$ values from the limited site-wide dose assessment (the last column in Table 5-12 and Table 5-13) as the cleanup goals for streambed sediment. These values are substantially less than those developed for the base-case recreationist scenario

[14] As noted previously, surface soil may or may not be remediated in Phase 1 of the decommissioning. However, it is possible that characterization performed early in Phase 1 could identify surface soil contamination that would warrant remediation to reduce radiation doses during the period between Phase 1 and Phase 2 of the decommissioning. In the unlikely event that this situation developed, the areas of concern would be remediated in Phase 1.

and are considered to be supportive of any approach that may be selected for Phase 2 of the proposed decommissioning.

As noted in the discussion on the ALARA analysis results, DOE expects that the actual levels of residual radioactivity would turn out to be less than the DCGLs used for remediation, i.e., these cleanup goals, owing to the characteristics of the remediation method to be used.

### 5.4.2 Refining DCGLs and Cleanup Goals

The calculated DCGLs for 25 mrem per year and the associated cleanup goals would be refined as appropriate after the data from the soil and sediment characterization program to be completed early in Phase 1 of the proposed decommissioning becomes available. These data are expected to provide additional insight into the radionuclides of interest in environmental media and the depth and areal distribution of the contamination. Such information could, for example, lead to deleting one or more radionuclides from further consideration in the Phase 1 cleanup or lead to more realistic source geometry for development of DCGLs for surface soil contamination. Analytical data from the subsurface soil characterization measurements being taken in 2008 could also provide information to help refine the subsurface soil DCGLs.

If evaluation of the new data leads to refinement of the DCGLs and cleanup goals, then this plan would be revised accordingly to reflect the new values. Since such a change could affect the project end conditions, the plan revision would be provided to NRC for review and input prior to issue following the change process described in Section 1.

### 5.4.3 Use of a Surrogate Radionuclide DCGL

A *surrogate radionuclide* is a radionuclide in a mixture of radionuclides whose concentration is easily measured and can be used to infer the concentrations of the other radionuclides in the mixture. If actual radioactive contamination levels of the surrogate radionuclide are below the specified concentration, then the sum of doses from all radionuclides in the mixture would fall below the dose limit.[15]

The tables in this section do not provide $DCGL_W$ values for a surrogate radionuclide because available data on radionuclide distributions in soil and sediment are not sufficient to support this. However, surrogate radionuclide $DCGL_W$ values for the cleanup goals would be developed and incorporated into this section if evaluation of additional characterization data shows that Cs-137 or another easy to measure radionuclide can be used effectively as a surrogate for all radionuclides in source soil, subsurface soil, and/or streambed sediment in an area.

### 5.4.4 Preliminary Dose Assessment

Preliminary dose assessments have been performed for the remediated WMA 1 and WMA 2 excavations. These assessments made use of the maximum measured

[15] Guidance on the use of surrogate measurements provided in Section 4.3.2 of NUREG-1575, *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)* (NRC 2000) would be followed.

radioactivity concentration in the Lavery till for each radionuclide as summarized in Table 5-1, and the results of modeling to develop DCGLs for 25 mrem per year as shown in Table 5-8. The results were as follow:

WMA 1, a maximum of 1.0 mrem a year

WMA 2, a maximum of 0.08 mrem a year

Given the limited data available, these results must be viewed as order-of-magnitude estimates. However, they do suggest that actual potential doses from the two remediated areas are likely to be substantially below 25 mrem per year.

### 5.4.5 Final Dose Assessment

As noted previously, DOE would perform a dose assessment for the residual radioactivity in the WMA 1 and WMA 2 excavated areas using Phase 1 final status survey data. This assessment would use the same methodology used in development of the subsurface soil DCGLs to estimate the potential radiation dose using the actual measured residual radioactivity concentrations. The results of the dose assessment would be made available to NRC and other stakeholders. Note that a more-comprehensive dose assessment that also takes into account the Phase 2 sources may be performed in connection with Phase 2 of the proposed decommissioning, depending on the approach selected for that phase.

## 5.5 References

**Code of Federal Regulations**

10 CFR 20, Subpart E, *Radiological Criteria For License Termination (LTR)*.

10 CFR 20.1003, *Definitions.*

**DOE Orders**

DOE Order 450.1, *Environmental Protection Program,* including Changes 1 and 2. U.S, Department of Energy, Washington, D.C. January 15, 2003.

DOE Order 5400.5, *Radiation Protection of the Public and the Environment*, Change 2. U.S, Department of Energy, Washington, D.C., January 7, 1993.

**DOE Technical Standards**

DOE Standard 1153-2002, *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota.* U.S, Department of Energy, Washington, D.C., July 2002.

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